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THE STUDY EXAMINED THE DISPLAY AND RESPONSE CHARACTERISTICS BY WHICH A STUDENT CAN INTERACT WITH A SUBJECT MATTER DISCIPLINE. IT ASSUMED THAT THE STUDENT-SUBJECT MATTER INTERFACE IS A FUNCTION OF THE STIMULUS AND RESPONSE PROPERTIES OF THE SUBJECT MATTER AND THE LEARNING REQUIREMENTS OF THE KIND OF BEHAVIOR BEING TAUGHT. CHAPTER ONE COVERED THE BACKGROUND OF THE PROBLEM AND THE APPROACH. CHAPTER TWO COVERED SUBJECT MATTER IMPLICATIONS FOR AN INTERFACE, INTERFACE ASPECTS AND INSTRUCTIONAL REQUIREMENTS, AND POSSIBILITIES OF A GENERAL PURPOSE STUDENT-SUBJECT MATTER INTERFACE. CHAPTER THREE DISCUSSED VISUAL COMMUNICATIONS, AUDITORY COMMUNICATIONS, AND RESPONSE DEVICES. CHAPTER FOUR DISCUSSED PRINCIPAL TASKS, PROBLEMS FOR INVESTIGATION, AND SUPPORT TASKS. (HB)

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THE INTERFACE BETWEEN STUDENT AND SUBJECT MATTER

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STUDENT AND SUBJECT MATTER

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Chapter I

INTERFACE CONCEPTS

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Preface

It is the purpose of this report to examine the dimensions along which subject matter can be presented to a learner and the dimensions along which he can respond to it and work with it in the course of learning. In engineering, the term "man-machine interface" is commonly used to describe the means by which a human comes into contact with a machine. In engineering psychology, much work has gone into the experimental analysis of the appropriate display and response characteristics by which a human can communicate with the machines and provide an optimal man-machine unit or system.

The concern of this report is similar to this to the extent that it examines the display and response characteristics by which a student can interact with a subject matter discipline. Borrowing from engineering terminology it seems appropriate to say that this report is concerned with the student-subject matter interface. Chapter I introduces the problem, its background, and the approach taken.

Part A

Introduction

When one thinks of the problem of presentation of subject matter to the learner, one thinks of the ubiquitous term "instructional media," which conveys the range of materials, such as books, tape recorders, and audiovisual aids, by which subject matter is displayed to the student. The primary contact of the student with his subject matter is through the printed page with supplementation by audiovisual aids and field and laboratory experiences. Despite all the service that printed materials and traditional aids have provided, it seems appropriate, in light of present engineering technology and behavioral science, to examine new possibilities for providing interaction between the student and his subject matter environment. It seems possible to present the learner with ways of seeing and manipulating his subject matter which extend and enrich his contact with it, and to form a learning environment in which subject matter dimensions are less drastically reduced than in a primarily paper and print learning environment.

In broad outline, a learning environment consists of the display of the subject matter to the student, controls or manipulanda (a pencil or a teaching machine) by which the student works with the subject matter, and some logic between the display and controls. The term interface, as used in this report, comprises the display media and controls with which the student is in direct contact. The display consists of information inputs to human sensory channels. The controls consist of transducers for converting human responses so they can be detected. If the objective of a teaching sequence is the manipulation of numerical or alphabetical symbols, the combinations of sense modalities which are required and the manner in which students should manipulate these stimuli in order to learn to generalize and apply their competence to a wide range of future instances must be considered. The manipulanda are related to the nature of the student response, the kind of manipulation required by subject matter characistics, the nature of the particular learning process, and the degree of subject matter competence to be attained. For example, concepts of more or less, of speed and acceleration, of rate of change in functional relationships as related to the terms of an equation, and conceptual models in science may be taught best if the student can operate a display in which the results of manipulating a variable are shown or fed back in a dynamic fashion in terms of its influence on related variables or outcomes. This feedback requirement is an integral part of the display and response logic of an instructional interface. Feedback characteristics are dictated by the kind of logic (both subject matter and teaching logic) that is established between student response to the display and a change in the display as a result of the response.

The responsive relationship between subject matter display and manipulation of it by the learner is one of the essential aspects of the student-subject matter interface. A student learns by manipulating the objects and concepts in his environment; the environment is responsive to his manipulation and in some way the student is informed of the results of his subject matter operations. Subject matter connections, subject matter principles, and approaches to subject matter problem solving are learned from manipulation of events, real or symbolic. It is a basic premise of this report that since the manipulation of subject matter events is the primary means by which the student learns, the manipulation should take place on the basis of a wide range of display and response modes. These modes are dictated by subject matter characteristics and requirements of the learning process and made possible by the application of modern engineering developments in display and response technology. Instructional environments, as a result, are less limited and less impoverished than is the case with much present instruction by the paper and pencil emphasis of most instructional materials.

The logic of the instructional environment is the relationship between display, response, and feedback display. This logic is a function of (1) the properties and structure of the subject matter, e.g., the consonant b has the sound /b/, 11 plus 1 are 12 in certain systems, or rate = $\frac{\text{distance}}{\text{time}}$, and (2) the teaching strategy and instructional requirements demanded by the kind of behavior being taught, e.g., the aptitudes and prior skills with which the student enters the instructional situation, the degree of accuracy or precision required before reinforcement occurs, or the kind of error-correcting prompts that are supplied. The logic is built into a workbook, into programmed instructional material, or into the computer logic of a computer-based instructional device. This report, as will be seen, assumes computer-based logic of some kind behind the display and response interface. However, the emphasis of the report is upon display, response, and feedback equipment and media and not upon computer operations. The present state of computer technology and of instructional practice indicates that computers can handle the problems posed to it by instructional requirements, and that the pressing need is for specification of the display and response requirements to be provided for the learner.

Part B

The Background of the Problem

The notions expressed above grow out of recent activity in education, psychology, and engineering. These converging lines of endeavor provide a rich background for this report.

Re-examination of the Technical and Theoretical Bases of Audiovisual Instructional Materials

In recent years, there has been much research and development activity on instructional media spearheaded by the Title VII NDEA program and the Department of Audiovisual Instruction of the National Education Association. The Technological Development Project, under the direction of James D. Finn, has produced a series of papers which review the history of educational technology (Anderson, 1961; Saettler, 1961), available teaching machine devices and programmed materials (Finn & Perrin, 1962), the use of audiovisual instrumentation (Finn, Perrin, & Campion, 1962), and design problems involved in development of instructional equipment (Leverenz & Townsley, 1962). In special supplements to the Audiovisual Communication Review, behavioral scientists have considered the implications of learning theory (Meierhenry, 1961) and of research in perception (Hochberg, 1962) for audiovisual utilization. In the latter volume Hochberg suggests the possibilities of dynamic, pictorial displays in education and their potential for the control of student attention. He points out the possibility of research in and development of visual displays which achieve control of visual attention in a way similar to the attention brought about by "good composition" of a picture. The scientific study of such aspects of display for educational purposes has had little history. Carpenter (1960) has discussed the necessity for exploratory research on the capabilities of new communication technology, such as television, for mediating educational experiences. These writers and others indicate an increasing concern of audiovisual specialists with defining more rigorously the principles underlying their work.

Programmed Instruction

Within the past ten years programmed instruction has focused the interest of scientists studying learning on the instructional process, and the instructional sequence has increasingly become a matter for experimental investigation. The concepts underlying programmed instruction have also forced the behavioral analysis of subject matter knowledge and skill (Lumsdaine & Glaser, 1960; Filep, 1963; Glaser, 1964a). The work to date has been restricted by the adoption of stereotyped presentation formats and the imposition of the paper and print media. Significant advances can be made by research and development carried out in instructional environments where display and response capabilities provide greater flexibility for adaptation to subject matter properties and learning requirements (Moore, 1963; Skinner, 1961; see section on computers below).

Subject Matter Modernization and Reanalysis

The activity of subject matter scholars in analysis of their disciplines for teaching has been a welcome trend in education. In science, mathematics, English, social studies, reading, and foreign language instruction, new displays and means of interacting with the subject matter, requiring simulation and manipulation of subject matter situations, have been encouraged. Foreign language instruction was one of the earliest to adopt mechanized auditory presentation. Unfortunately, the method was adopted before it could be influenced by the concepts of programmed instruction.

Computer-based Instructional Systems

The interest shown in computer-based instructional systems has led to some potentially fruitful developments (Coulson, 1962). While the emphasis in automated instruction has been on internal computer-based logic (Bitzer, Braunfeld, & Lichtenberger, 1962; Stolurow, 1961), examples are now available which show innovations in computer-controlled displays. Licklider (1962) for example, used oscilloscope displays to teach German and graphic representation of equations, and Uttal (1962) employed an electroluminescent character generator in teaching stenotype. The work of Licklider is a good illustration of the potential of new technological developments for an instructional interface. In a computer-based arrangement, the student worked with a typewriter response unit and an oscilloscope display unit. As a means of developing an understanding of the relations between symbolic and graphical representation of mathematical functions, the student typed coefficients of an equation on the typewriter, and the oscilloscope screen displayed the corresponding curve. The arrangement permitted the student to use the automated context for exploration of the concepts he was learning. (Such a setup also provides the possibility that simple, computer language can be developed which a teacher might learn to use for designing teaching sequences in an automated classroom.)

Presentation Modality

Chapman and Carpenter (1962) indicate that the major research issue in the automation of instruction is the problem of presentation modality. They ask for research on the appropriateness of modality of presentation for different concepts; in other words, are certain concepts better learned visually, auditorily, or by combinations of modalities? Teager (1962) indicates the importance of the development of graphical input and output facilities in automated instructional systems that can remove the student from the restrictions of keyboards, limited sets of characters and one-dimensional inputs. He points out that in the use of modern technology and computer-based instruction, major innovations are required in the form of input and output consoles. "To make it effective and efficient, much thought must be given to psychological, mechanical, and programming considerations. Slavish adoption of standards that were developed for essentially different usages will only delay the day of more fruitful human-machine cooperation"(p.280).

Man-computer Communication

Related to the above has been the work by mathematicians, computer technologists, and engineers on control and display consoles for interaction with high-speed computer systems. Experimental consoles have been constructed for mathematical analysis, engineering drawing and testing, and linguistic analysis (Licklider & Clark, 1962; Stotz, 1963; Sutherland, 1963). These developments, which will be discussed in more detail, provide the physical equipment capability by which subject matter can be displayed to and manipulated by the student.

Engineering Psychology

Work in the field of engineering psychology and human engineering has been referred to above. However, the major significance of this area for a student-subject matter interface is that knowledge has been codified with respect to the optimal conditions and limits for the interaction of humans and machines, for the presentation of information in various sensory modalities, and for the design of response mechanism (Morgan, Cook, Chapanis, & Lund, 1963).

Categories and Properties of Human Behavior

Increasingly, psychologists have begun to analyze the behavioral properties of human performance. In the past more emphasis was devoted to learning phenomena and individual difference effects. However, as psychologists turned their attention to training and education (Glaser, 1964a), they were faced with the necessity for behaviorally analyzing the tasks on which they were working; this is a necessity in dealing with real-life tasks and real subject matter. In contrast, in the psychological laboratory, an investigator decides upon and constructs or preselects an experimental task which has stimulus and response characteristics pertinent to his problem. More and more experiences are indicating the importance of research which considers instructional variables in terms of the characteristics of the properties of the tasks to be learned. Along these lines Bruner (1960) has emphasized the structure of subject matter. Gagné (1964) has related the characteristics of a variety of learning tasks (response differentiation, association, multiple discrimination, behavior chains, class concepts, principles, and strategies) to the description of educational objectives and the kind of learning conditions required for different objectives. Skinner (1957) has consistently attempted to consider the properties of behavior in conjunction with this experimental analysis. Lane (1964) in language learning and Mechner (1964) in science instruction carry forward Skinner's emphasis on the analysis of behavior. Carroll (1964) identifies the stimulus-response classes that require specification in reading instruction. Melton (1964) has edited a book on the categories of human learning to explore the utility of past and possible future categories for the scientific analysis and technology of human learning. Fleishman

(1962) suggests further that task properties change as learning progresses and that students may call upon different combinations of abilities at different stages of learning.

The significance of these studies is that learning technology and instruction must consider the stimulus (display) and response characteristics of the learning task and relate these stimulus and response properties to the effective conditions for learning. The increased specificity of the different categories of human learning should suggest a wide range of stimulus and response requirements. Research and development along these lines leading to effective instructional conditions will require an increased range of display and response mechanisms which can permit the freer use of variations in stimuli, responses, and modalities as dictated by learning categories, different learning stages, and individual differences in aptitude and background.

Curiosity and Exploratory Behavior*

Within the past decade, an increasing amount of research effort has been directed to the study of behavior generally labeled as curiosity and exploration (Fowler, 1964; Berlyne, 1960). Prior to 1950, research on curiosity and exploratory behaviors was all but absent except for a few isolated instances. In infrahuman studies, research has been aimed at the discovery and identification of variables which serve to elicit and maintain behavior of this kind in the absence of conventional motives such as hunger or thirst or other conditions of deprivation. The specific responses which were observed were such behaviors as orienting, approaching, investigating, manipulating, etc. The significant variables influencing such exploratory responses have been characterized as stimulus objects or patterns that are novel, unfamiliar, complex, surprising, incongruous, asymetrical, etc. All these aspects can be generally described as change in the stimulus complex displayed to the individual. Research has indicated that the strength of exploratory behavior that is elicited is positively related, within limits, to the degree of change in the stimulus situation provided by the novel, unfamiliar, or incongruous stimulus situations introduced into the environment. Too great or too abrupt a change, however, is disrupting and may preclude exploration. In complex situations an individual's encounters change by way of his interaction with or manipulation of the elements of the stimulus pattern. Such interaction provides the stimulus change which can elicit curiosity and exploratory behavior.

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*We are indebted in this section to a working paper prepared for this project by Professor Harry Fowler of the University of Pittsburgh.

Investigations have also demonstrated that behaviors are learned that lead to a change in the stimulus display. Thus, in addition to stimulus change eliciting exploratory behavior, experiments, primarily with animals, show that organisms will respond in order to secure novel, unfamiliar stimuli--in general, stimulus change. Such findings have been obtained for a variety of response modes, e.g., auditory, visual, and proprioceptive. The stimulus change, not only the initiating stimulus, can occur in a variety of modes. For example, exploratory manipulative responses may be learned on the basis of the changes in proprioceptive stimulation which accompany them (Harlow & McClean, 1954; Harlow, 1955). In general these findings demonstrate that stimulus change or sensory variation may be employed to selectively reinforce, and thereby strengthen and maintain, behaviors which result in stimulus change, and that this change or variation in the stimulus situation will serve concomitantly elicit exploratory behavior. Stimulus change as a reinforcer appears to be quite similar in its operation to other kinds of reinforcing stimuli, and the phenomena of acquisition and extinction, the effect of magnitude of reinforcement, delay of reinforcement, and schedule of reinforcement influence exploratory and curiosity behavior as they do other learned behavior.

With respect to the student-subject matter interface, this work suggests that a student's curiosity and explorations may be both elicited and selectively maintained in an instructional (learning) environment which provides for variation and change in both the stimulus characteristics of subject materials confronting the student and also the responses required of him by these materials. Development of an appropriate interface which could provide a relatively continuing, manipulative interaction between the student and subject matter stimuli would permit a continuous flow of variation in both student stimulation and response requirements. An instructional sequence could be programmed so that a pattern of change is provided in stimulus and display characteristics. In addition, the reinforcing effects of stimulus change could be used to reinforce desirable subject matter competencies. Along these lines, research and development with a range of display and response capabilities, can investigate the effects of curiosity and exploratory behavior as they relate to student learning.

Part C

Approach

The approach to an examination of innovations in the student's learning environment which is taken in this report postulates that the student-subject matter interface is a function of primarily two aspects: (1) The stimulus and response properties of the subject matter. For example, learning to read aloud demands a printed, verbal stimulus situation, a vocal response, and some means of detecting the accuracy of this spoken response; learning to listen demands an auditory stimulus and listening response which is measured in some way by determining the results of having listened, such as carrying out spoken directions or summarizing the meaning of spoken communication; and learning to carry out the computational operations of multiplication demands presentation of a written or printed set of numbers and a written response, or, at a later stage, a keyboard response on a calculator. (2) The learning requirements of the kind of behavior being taught. For example, in learning precise accents in a language laboratory, some procedure is required for detecting and evaluating the correctness of pronunciation so that the student is given informational and reinforcing feedback in order to facilitate his increasing accuracy; the teaching of language pronunciation further may require the continuous adjustment of what is accepted as a correct response as learning proceeds. Many ways of pronouncing a correct French r may be acceptable for a beginning student while fewer ways are acceptable for the more advanced student. In teaching handwriting, it is often necessary to provide the student with guide lines and lines to trace which are gradually removed as skill increases. Furthermore, the terminal educational objectives of a lesson influence the way in which subject matter is presented. If the objectives require that a certain body of knowledge be memorized, that subject matter may be presented and learned in one fashion; however, if the objectives require that the student learn to solve problems in his subject matter or deduce its further implications, the material will be presented in a different way. Both of these aspects, the properties of the subject matter and the manipulations of the subject matter required for learning, dictate the environment presented to the student for effective learning.

In order to discover these properties and requirements, what is necessary is the application of techniques for analyzing subject matter properties and for analyzing the differentiating characteristics of kinds of behaviors to be learned. The procedures for carrying out these kinds of analyses are at the present time far from well worked out and available for unambiguous use (Bloom, 1954; Gagné, 1964; Melton, 1964; Stolurow, 1964).

The design of innovations in an instructional interface, while dictated by the above considerations, is delimited by the state of engineering technology with respect to techniques for displaying information and for detecting human responses. For example, in the present state of equipment development, it may be feasible to display alpha-numerical characters on a television tube; the student can change the nature of this display by selecting keys on a typewriter. It may be less feasible to have the student change the display by having his spoken response detected by voice recognition equipment. A further possible delimitation is the capability of a computer-like device to provide the necessary logic that mediates between display and response, so that a certain kind of response results in the presentation of a certain kind of display.

Several aspects, then, influence the development of student-subject matter interfaces: subject matter properties and learning characteristics, equipment capability, and mediating logic devices. These latter devices essentially are computers. The emphasis of this report is on the properties of the interface with which the student interacts with the subject matters. Implicit in this emphasis is the belief that there has been much less development with respect to subject matter display and response interfaces than there has been for computers. It is further assumed that the demands placed upon a computer by real-time use in an instructional situation are probably within computer capabilities. What is required are ways for the student to communicate with the computer. Not to be minimized in this context, however, is the significant amount of supplementary computer programming, frequently called software, required in programming a computer for instructional purposes. Computer capabilities also provide the means whereby a computer-based instructional interface can be used for practical teaching purposes and significantly, can also be used for the detection, monitoring, and collection of measures of student learning in order to study important variables of human learning and the instructional process.

With the emphases just described in mind, this report approaches the task of examining innovations in the student-subject matter interface in the following way: First, materials in several subject matters are examined and analyzed with respect to stimulus and response properties and learning characteristics. Second, a survey is made, on the basis of available literature and field trips of engineering equipment developments for information display and response detection. Third, the subject matter and equipment analyses are considered together in the development of suggestions for an interface research and development program and for the kinds of problems that must be explored to answer questions about the learning and instructional process and engineering questions for interface design.

Assumptions and Limitations

Certain assumptions which limit the scope of this report should be stated explicitly. The problem of primary concern is the interface and its use for subject matter stimulus display, subject matter manipulation, reordering, rearranging, etc., and response reception and feedback. Essentially this involves the way and the instrumentation by which the student communicates with the logic of the lesson plan. It is assumed that computer capability to handle this logic is adequate and available. Computer software aspects involved in programming the computer are not examined in detail, but are mentioned briefly in Chapter 4 since they will be a significant aspect to be studied and implemented, e.g., programming procedures, appropriate languages and associated compilers for instructional programming in various subject matters. Also not highlighted in this report are the problems associated with programming (in the sense of programmed instruction) of instructional sequences and providing appropriate conditions for learning. The instructional lessons which must be prepared for study will need to consider this aspect in relation to the interface capabilities.

Interface requirements in this report are oriented toward children in the elementary school grades or younger, essentially from nursery school through the sixth grade. Whether this emphasis is best as a starting point for considering automated learning environments in education is a matter of opinion. The following, however, do seem to be points in favor of an examination of the problem for young children: (1) Some work is already going on in man (adult)-computer interaction, but work which considers the elementary grades may provide easier material with which to work out initial problems (although when one analyzes the complexity of multiplication and division in relation to the capabilities of a child, the point is debatable). (2) It is being increasingly recognized that the potential of young children can be encouraged with devices (like creative toys) which are designed for their level of motor development. (3) Application of knowledge from the science of learning to new instructional media might be more feasible at stages of early learning in comparison to more complex adult learning. (4) Learning in nursery school and kindergarten which is not involved with learning particular subject matter skills, like reading and arithmetic, but more related to general habits of thinking, imagination, and creativity, may be enhanced by the use of new media.

Despite this last statement concerning the learning of very young children, the orientation of this report is toward the teaching of subject matters, such as topics in science, reading, writing, and arithmetic. There has been too much of a tendency for educators and psychologists to concern themselves with teaching for the more abstract and "higher things" in education, like problem solving, creativity, and intuition. The interest in such abstractions has often led to the neglect of knowledge fundamentals upon which these higher order behaviors can be imposed. It is an assumption of this report that an expanded learning environment can more adequately investigate how attitudes of resourcefulness, concentration, interest in the subject matter content can be provided in the course of school instruction.

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Chapter II

SUBJECT MATTER AND INSTRUCTIONAL MATTER

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Preface

The general problem to be considered in this chapter is how subject matter properties and requirements for learning can impose conditions upon the design of an instructional interface. To this end, Chapter II attempts to do the following: (1) analyze the stimulus and response requirements of arithmetic concepts and computations, elementary lessons in reading, and elementary science; (2) examine some instructional procedures to see how their requirements might be implemented in an environment which will provide a wide range of stimuli and manipulative responses; (3) provide an example of a specific learning sequence in which the designers are not limited by conventional instructional media; (4) discuss the possibilities of a general purpose interface which can meet the stimulus and response requirements of Parts A and B of this chapter. The consideration of subject matter stimulus and response requirements, procedures for effective learning, and technological feasibility should provide basic information for the design of instructional tools which can help the teacher cope with the severe educational problems of our day.

Part A

Subject Matter Implications for an Interface

The illustrative subjects to be considered are mathematics, reading, and science, all at the elementary school level. The question to be answered is how do these subject areas impose conditions upon the design of an automated interface. Examples will be presented to add clarity to the arguments. These examples are not intended to be most representative or most important in the subject areas from which they were drawn. Outlines of student skills in the areas of mathematics, reading, and science will be presented. After each subject area is discussed, a summary of the stimulus and response requirements for that area will be presented. A final summary covering the subject matter implications will also be made.

Mathematics

Mathematics in the primary grades involves the following subject matter behaviors: (1) making the correspondence between sets of objects and a numerical representation (usually an oral representation at first); (2) discrimination of numeral shapes; (3) performing arithmetic operations as defined by the number systems; (4) recognizing patterns in the operations which can be performed with numbers and objects; (5) discriminating spatial properties, and (6) relating numbers to the properties of space. In addition to the above classes of learning activity, the student must acquire the computational skills relevant to these concepts. This above list of subject matter objectives was compiled after surveying approximately eight courses in elementary mathematics which are currently used in the United States. These include:

1. Arithmetic - Laidlaw Company
2. Greater Cleveland Mathematics Program - Science Research Associates

3. Elementary School Mathematics - Addison-Wesley Company
4. Modern Arithmetic Through Discovery - Silver-Burdett Company
5. Sets and Numbers - Blaisdel Publishing Company
6. Math Workshop for Children - Encyclopedia Britannica Press
7. The New Arithmetic - McCormick-Mathers Company
8. Learning To Use Arithmetic - Heath Company

A complete list of topics introduced with examples would run into many pages and hundreds of items.

Subject Matter Behaviors

The following table gives an example of a response which may be asked of a student for each of the above:

Behavior	Example
1. Making the correspondence between the sets of objects and a numerical representation.	There are three toy horses on a table. The student is asked how many horses are on the table. Either holding up three fingers or saying "three" would be an adequate response.
2. Discriminating numeral shapes.	The student is shown three toy horses and presented with a choice of visual numerals. He is asked, "How many horses are there on the table?" He should select the numeral 3.
3. Performing arithmetic operations.	27 x 3 = ? The student should be able to perform the operation using chips, pennies or an abacus.
4. Recognizing patterns in the operations which can be performed with numerals and objects.	If presented with the sequence 3, 6, 9 the student should be able to respond with 12 as the next number of the sequence.
5. Discriminating spatial properties.	If presented with a suitably chosen rectangular area to be covered with a choice of non-overlapping smaller shapes such as circles, ragged pieces and squares.

6.	Relating properties of number to properties of space.	If the student is presented with a rectangle and asked to find the number of small squares it would take to cover the rectangle, he will measure the length and width and multiply to find the squares required.

Each of the above subject matter categories will be considered below in terms of the interface requirements for stimulus presentation and student response.

1. Making the correspondence between sets of objects and a numerical representation. For the early stages of education in developing the relationship between sets of objects and number representations, the instructional environment usually presents arrays of objects such as round discs, sticks, or toy animals. The student then matches the numerals with the proper set of objects by various response modes, e.g., by writing a numeral, selecting from alternative numerals in response to directions which essentially ask, "Which group has three dogs? How many things are in front of you on the table?" For very young children who have not yet learned to write the numerals or even to discriminate them in a visual display, an oral detection capability would be a requirement for the interface.

2. Discriminating numeral shapes. In order to teach the numerals which correspond to the number property of sets of objects, the interface must have a visual display mode. When the student has mastered the ability to relate arrays of three-dimensional objects to a number, the three-dimensional object presentation can be succeeded by a two-dimensional visual presentation of arrays of dots, squares, pictures of animals, lines, etc. The student response can now take place on a two-dimensional surface like a keyboard console. For example, the early lesson in the correspondence between a numeral and the number of objects it represents might involve a display of objects and a keyboard with the numerals on it. A sequence of object-numeral displays can be presented to the student with display and response variations designed to facilitate such learning effects as discrimination between set numerosity or generalization to sets of objects of different kinds having the same numerosity. Displays can be chosen which are reinforcing on the basis of the student's preference for certain

pictured objects. The subject matter of mathematics determines that certain stimuli must be presented in the form of numerals and sets of objects; the manner of presentation is determined by the conditions for effective human learning.

3. Performing arithmetic operations. Once the correspondence between numbers and numerals is mastered by the student, little new interface capability is required for the lessons which develop the relationship between numbers. For example, to teach the fact that 3 x 4 = 4 x 3 = 12, the same visual display of objects, pictures of objects and numerals may be used as for teaching the correspondence between numbers and numerals. The visual display of a number line, the animation of lessons, the possible use of color and other attention-maintaining features are more related to the problem of efficient teaching than to the subject matter requirements.

4. Recognizing patterns in the operations that can be performed with numbers and objects. Wirtz, Botel, and Sawyer (1962) have emphasized that an important area of learning in mathematics is the search for pattern in numerical and spatial relationships and that elementary students should engage in the search for pattern in graded sequences of activity. Through this search for pattern, students can be led to considerations of operations involved in addition, subtraction, multiplication, division and various combinations of these operations. In addition, the student can be led to generate his own more sophisticated relationships which may prepare him for more advanced lessons. The generation of various patterns is a new requirement for the interface in arithmetic lessons. For example, the typical activity in the Math Workshop (Wirtz et. al., 1962) is "What's My Rule." A series of numbers may be presented as follows:

"If you say 3 7 1 4 9 2 17 8 5 10
I answer .... 8 20 2 11 26 5 50 ? ? ?"

The student is asked,"Find the rule and finish the answer line." The rule in the above case is multiply by 3 and subtract 1. A student may be able to finish the line without the verbal expression for the rule and thus be led to the formal arithmetic operation in terms of a familiar problem which he has solved. To complete the exercise above the student need only put 23, 14 and 29 beneath 8, 5, and 10, respectively. Other exercises may involve the use of number lines and various two-dimensional number arrays. In some cases, the patterns may involve geometrical shapes and need not have numbers at all. By a graded sequence of pattern difficulty, young children can become quite sophisticated in their ability to continue the patterns without the verbal skill required to describe them. In order to accomplish this, the interface should have a visual presentation capability and a student response mode which allows the student to select elements which continue the pattern. Prompting displays might be desired to provide search cues to elicit appropriate responses.

5. Discriminating spatial properties and
6. Relating properties of number to properties of space.

The properties of space and the relation between numbers and the properties of space takes the student into the areas of geometry and functional relationships. The student learns to recognize a sphere, a cylinder, a square and other geometric figures. At some point, he is taught to describe these figures and surfaces and volumes in the precise language of numbers. For example, the student is able to identify a square, construct a square with straightedge and compass (Hawley & Suppes, 1951), and eventually define a square in terms of the numerical properties of its lines and angles.

In order to enable the student to deal with the properties of space, the following requirements for an interface are suggested:

1. The interface should develop the ability of the student to respond to three-dimensional problems. For example, the student may be shown a sphere and asked, "This object is a ______________________?" The student would be expected to respond with the word sphere.

2. The interface should develop the ability of the student to abstract the properties of three-dimensional figures when presented with a two-dimensional stimulus. For example, a screen or book may show a sphere in color and in perspective. Before the student are several three-dimensional shapes. The student is asked, "Which of the objects before you is the same as (represented by) the picture on the screen?"

3. The interface should develop the ability of the student to use two-dimensional representations to visualize the properties of three-

dimensional objects. For example, when shown a drawing of a three-dimensional object he has not before seen, the student should be able to construct a model of the three-dimensional object.

4. The interface should develop the ability of the student to use the two-dimensional representation to develop the point by point properties of space. This behavior covers the formal instruction in such topics as the calculation of surface areas, volumes, slopes, and centers of mass, by direct calculation or measurement on models. While seemingly beyond the elementary level, many aspects of these problems can be taught to young students through the use of manipulable models and representations.

Summary of Stimulus and Response Requirements. In order to meet the above subject matter requirements, a summary list of interface provisions would include:

1. The means of presenting numerals, symbols and drawings.
2. The means of presenting and detecting numbers of objects.
3. The means of detecting which of a group of objects are placed on a surface.
4. The means of presenting problems which require sequential operations and determining the sequential response of the student.
5. The ability to detect constructed responses such as the construction of a square with a ruler and compass, the ability to guide constructed responses involving lines.
6. Provision for presenting auditory as well as visual stimuli (e.g., for instructing very young students) and the detection of oral responses.

Reading

The reading program discussed here envisions bringing the student to the level of reading ability where he should be able to read aloud most of the words in the daily newspaper (not counting proper names) by phoneticising unfamiliar words. Of course, ability in texting does not indicate mastery of the meaning of the word or the ability to use the word freely in constructed responses. The mastery of word meaning and word usage is another part of the language arts.

Sequence of Skills in Reading Instruction. In learning to read the student must acquire the ability to discriminate between the letters of the alphabet and he must be able to generalize to the many ways in which letters are formed. In the usual reading course the student must be able to respond with the appropriate sounds or various letter combinations, both regular and irregular. In devising a course of instruction, there are three major areas which must be considered. These are: (1) the entering behavior of the student with special attention to his vocabulary, psycho-motor skill, and ability to follow verbal instructions: (2) the linguistic structure of the language, and (3) the psychological conditions for acquiring and maintaining the needed responses.

While any instructional program must deal with such considerations as these, in reading they assume greater significance because of the background of investigation into each of the three areas and because of the lack of any convergence of opinion regarding the results and implications of these investigations. The situation is interpreted by Carroll (1964) in the light of the work in programmed instruction:

> Some studies of programmed instruction suggest that different orders of presentation have alarmingly small effects. Thus, of what help is it to 'program' the order of presentation of the various components of reading behavior? Why not simply present a variety of words and their pronunciations and allow the child to infer, for that matter? Essentially, of course, that is what is done in some kinds of contemporary reading instruction; but, in an effort to remedy the presumed inefficiency and failures of such a system, there are other systems which lay great stress on the programming of letter recognition and the development of grapheme-phoneme correspondences. At the present time, there is no adequate theoretical or empirical basis for deciding among these or other systems....
>
> For example, research in the field of reading does not enable us to say with certainty in what order the various processes in word recognition are best learned. To what extent is grapheme recognition prerequisite to the recognition of the whole pattern of a word? To what extent is it feasible to teach grapheme-phoneme response habits in the earliest phases of word-recognition practice? If this is feasible, should early teaching of grapheme-phoneme correspondences be based only on a selection of highly regular correspondences, or

> should the child be presented with a certain degree of irregularity and variety in order to condition him to the full range of irregularity of English orthography? These and many other questions arise from the kind of psychological and linguistic analysis of the task of reading .... (Pp. 350-351).

Grapheme-phoneme correspondences can be taught to very young children with presumably limited vocabularies as in O. K. Moore's typewriter program. Other programs such as Cynthia Buchanan's Programmed Reading (1963) clearly state that the program is designed for a child who can speak fluently and has a vocabulary larger than he is likely to encounter in reading instruction. Much of the confusion in competing methods of reading instruction seems to result from a lack of consideration of the entering behavior which each program assumes, often without explicit definition.

At any rate, Carroll's comment on the strategy of reading instruction will lay the basis for the approach taken here.

> Generally, we believe that teaching becomes a relatively straight-forward and simple operation, once an adequate analysis of the behavior to be taught has been made and a program of instruction has been planned which features each separate item to be learned in its proper order and in its proper behavioral setting. A direct rather than an indirect approach is to be taken. For example, a proper strategy for increasing vocabulary is to determine students' vocabulary needs by appropriate diagnostic testing, then proceed to teach the items identified, one by one, at some appropriate rate of introduction (p. 352).

Viewed in this light, an order of presentation of items which is developed in terms of the student's entering behavior is important to the design of instructional sequences. A linguistically-based sequence, while not necessarily the only desirable sequence, has the important advantage of setting forth the items of instruction according to a scheme of analysis which assures coverage of all the important aspects of language instruction and which can easily be integrated with a specification of entering behavior and be programmed according to a psychological analysis of the responses to be learned. For example, linguistically designed programs may indicate that words involving the short a sound, /æ / as in apple, should be introduced first (Buchanan, 1963). Carroll informs us that, "there is evidence ... that the teaching of the mechanics of speech reconstruction ... is best done with materials which are maximally meaningful to the learner, e.g., words that are labels of things of interest to the learner or very simple sentences that convey an interesting or useful message (p. 338)." The combination of these two precepts results in the use of am, an, ant, man, mat, tan, pan, fat, and fan in the first unit of instruction of Buchanan's Programmed Reading. The following instruction sequence which is due to Fries and reported by Markman (1963) shows the orderly coverage of the subject matter which is possible in a program designed from linguistic considerations:

1. Student learns that symbols represent sounds.
2. Student learns alphabet.
    a. Only capital letters first.
    b. Sequence--

        15 stroke letters
        5 circle letters
        6 combination letters

    c. Student learns lower case letters in order of their correspondence with upper case letters.
3. Student learns left to right movement of writing.
4. Student learns simple words for instant recognition. These conform to the pattern bad, bat, bud, bet, bit, man, mat, tan, pan, pie, am, an, fat, fan, etc.
5. Student learns words introduced in the following order:
    a. simple regular spellings (hat, hit)
    b. simple regular, irregular spellings (cup, son)
    c. simple irregular (who, me)
    d. compound regular (ship, with)
    e. compound regular, irregular (muff, dream)
    f. compound irregular (busy, mother)
6. Student learns to read sentence patterns as soon as possible.
7. Student has opportunity to use most interesting words as soon as possible (nose cone, re-entry).

In minor respects, this program differs from the Buchanan program of Sullivan Associates. Fries does not approve of the use of pictures while Buchanan's program uses pictures as prompts in discrimination training and as motivation for the students to continue working in the program. Buchanan uses a small array of sight words (words which do not conform to the sound which the student has been taught to match with a letter) to generate more natural sentences. Other stated aspects of the Buchanan program are as follows: The basic technique is that of stimulus generalization which she defines as written symbols used in one-to-one correspondence with their sound values so that the student can generalize within the system he has learned. Pictures are used motivationally and to help the student solve the discrimination problems. The stimuli chosen result from an attempt to enter into the world of the beginning reader. This beginning reader is one who is a fluent speaker whose vocabulary exceeds that of any first course in reading.

Buchanan Programmed Reading. The program is divided into a prereading, primary and second units. The detailed outline of the program follows.

> Programmed Prereading. At the end of the Programmed Prereading the student will know the following things:
>
> 1. The names of the letters of the alphabet (capital and small).
> 2. How to print all the capital and small letters.
> 3. That letters stand for sounds.
> 4. What sounds to associate with the letters: a, f, m, n, p, t, th, and i .
> 5. That letters are read from left to right across the page.
> 6. That groups of letters form words.
> 7. The student learns yes and no by sight, how to discriminate the words ant, man and mat from each other, and how to read the sentence I am an ant (p.2).

Programmed Reading (Books 1-8). With a gradually increasing list of words and letters, the student must achieve competence in the following activities:

1. Listening to a list of words and responding by raising one's hand according to instructions (e.g., "Raise your hand each time I say a word with an /i/sound.")

2. Word discrimination. The student is asked to read aloud pairs of similar words or to choose one of a pair of words which is indicated by a picture. (e.g., "Read aloud, *fan-pan*." Or, if shown a picture of a fan and the words *fan-pan* he should draw a line under the word *fan*.)

3. Dictation. The student is asked to write the first letter of each word in a list which is presented orally. (e.g., "Write the first letter of the word *Sam*."

4. Sound-Symbol correspondence. The student is asked to pronounce the sounds of individual letters when written on the board or to circle or write the appropriate letter when its sound is presented. (e.g., "What is the sound for the letter *t*" written or "Write the letter for the sound /t/.")

5. Reading aloud. At all stages the student is asked to read aloud stories using the words he has learned.

6. Written programmed exercises. The student must fill in letters according to a reasonable pattern using pictures and past learning as a guide. (e.g., A picture of a fish is shown and the student must complete this sentence: A __ish has __ins.)

The following progressions are used in the first series:

1. The student learns the consonant sounds in the following order (alphabet letter followed by phonemic symbol) *m*/m/, *n*/n/, *t*/t/, *p*/p/, *th*/θ/ /ð/, *f*/f/, *c*/k/, *s*/s/ /z/, *b*/b/, *ng*/ŋ/, *h*/h/, *sh*/š/, *d* /d/, *g*/g/, *r* /r/, *ch*/č/, *k*/k/, *l* /l/, *w* /w/, *v* /v/, *x* /ks/, *j* /j/, *y* /y/, *z* /z/, *qu* /kw/.

2. The student learns the vowel sounds in the following progression: *a* /æ/, *a* /ə/, *i* /ay/, *i* /i/, *e* /e/, silent *e*, *er* /ər/, *ar* /ar/, *e* /iy/, *al*/ɔ/, *a* /ɵ/, ay/ey/, u /ɵ/, o /a/, or /or/, ur/ər/.

3. The child learns eleven addition sight words (*on*, *the*, *yes*, *no*, *to*, *up*, *of*, *are*, *lamb*, *they*, *what*, *does*).

4. The student learns regular suffixes in the following progression: (suffix followed by sample word), -*ing*, *singing*;

-s, hits; -es, catches; -er, bigger; -ed, handed, fixed.

The rationale for the above progression choices is probably to develop a rich reading vocabulary of words familiar to the child. To this end the author occasionally departs from the linguistic progression of Fries.

Programmed Reading: Series 2 (Books 9-14). The following progression of topics is used for the second series of lessons:

1. The student learns the long sounds for the vowels.
2. The student learns the sounds for some double vowels.
3. The student learns the sounds for some vowel combinations.
4. The student learns the sounds for vowels whose sounds are affected by a silent e.
5. The student learns the soft sounds for g and c.
6. The student learns the sounds for suffixes such as -le and y.
7. The student learns to read words with silent consonants.
8. The student learns the sounds for some other irregular subclasses of letter combinations.

Interface Requirements for Reading Instruction. From the above detailed outlines of sequences of objectives of instruction in reading, some properties of an instructional interface can be stated. The instructional environment must be able to present the individual letters in such a fashion that the student can be asked to discriminate between stimuli which may be other letters or shapes such as triangles which are not in the English alphabet. Further, visual stimuli for the letter combinations must be presented to the student and the oral response of the student detected. Since the proper use of the student's entering vocabulary is important to a successful introductory reading program, the facility should have the means of detecting, recording, and providing instruction which is contingent upon the student's verbal behavior.

Almost all reading programs today contain instruction in phoneticizing. The student must make an approximate pronunciation according to some symbol-sound correspondence and then be able to identify a common word from the approximate pronunciation or have the approximate pronunciation shaped into the correct pronunciation. In order to deal with the problem of presenting examples of phoneticizing and to shape the student's approximate pronunciations there must be a sound display and detection capability.

In the beginning stages of reading instruction a high degree of prompting is required. Both visual and auditory prompts will be needed. For example, an H built into a picture of a house can be used as a prompt for the name or the sound of the letter H. As the student learns the letters the picture gradually fades from presentation to presentation until only the letter H remains. An auditory prompt may be the direct auditory presentation of a sound with a letter and fading of the sound intensity as the student latency of response becomes less until finally the auditory prompt is eliminated.

In other stages of discrimination and response training less direct prompts will be used, e.g., a preceding word familiar to the student may be used to prompt the pronunciation of a subsequent word as in the following sentence: "The principle reason is that he is invincible." Here, the word principle prompts the similar pronunciation of invincible.

Latency of response to the visual symbols is an important key to the pacing of prompts, introduction of new material and an increased rate of presentation. For example, the final stages of reading instruction involve oral reading by the student with correction when a student error occurs. Textual material may be presented at a gradually increasing rate. If a difficult word causes a student to pause in his reading, a prompt may be employed to assist the student to respond. In both of the above situations (increase of rate of stimulus presentation and assistance when an error occurs) the key to appropriate changes in the environment is the student latency of response. Thus, the measurement of student latency is a desired facility. In order to correct a misread or mispronounced word, voice-detection equipment must actually detect the words spoken and be able to compare the spoken word with the visual stimulus. Since most pronunciations are approximations of some standard or ideal pronunciation the instructional device must have the capability of accepting all responses within certain tolerance limits, rejecting all utterances outside the tolerance limits, and gradually decreasing the tolerance limits until a suitable final standard is reached. A sequence might be provided such that when a student mispronounces a word, the word would be correctly pronounced for the student and all other words removed from the visual display until the student has repeated the troublesome word correctly. The incorrectly pronounced words would be stored and displayed again to the student until he is able to pronounce them without error.

In summary, the subject of reading requires that an interface have the following characteristics:

1. Visual display mode for letters and other visual symbols and pictures.
2. Voice detection mode which can determine whether a letter has been correctly discriminated and correctly pronounced.
3. Response mode for the selection of graphic letters as responses and for the selection of graphic words as responses.
4. Voice detection mode which can ascertain correct word pronunciation with a certain tolerance and measure and record the latency of the response.
5. Prompting provisions for the early stages of training and prompting provisions which depend upon the latency of response in the later stages of training.
6. Stimulus presentation of printed words which varies both in rate and word range with the student's prior performance.

Science

Science makes the greatest demands upon the interface in terms of the range of material which must be presented (oscilloscope traces, oscillator tones, spring arrangements, black bodies, colors, solids, liquids, gases, balloons, air tables and much more), the range of manipulations which must be performed with these displays, and the range of student responses which must be accommodated. The two-dimensional display is used only in so far as the experience of the student has enabled him to abstract meaning from the multi-dimensional world which is the basis of the picture, the line drawing, or the model. A three-dimensional model is of greater use for the student because the degree of abstraction required is less than that needed when two-dimensional representations are used and the model may offer possibilities for student manipulation which a drawing cannot offer unless extensive simulation techniques are used. But, in science, even three-dimensional models are sometimes unable to carry enough information to meet the needs of the student. For example, a model of a salt crystal using sticks and balls is used to show the relative position of atoms and the spacing of atoms in the crystal. A young student will not be able to use this model until some means is found for him to appreciate the idea of scale, the forces between atoms, the manner in which the shape of a large crystal depends upon the atomic arrangement and other ideas. The student requires a range of experiences with the properties of atoms in order to make the kinds of responses which are expected after even elementary instruction in the atomic structure of matter.

Laboratory Work. Virtually every educator who writes on the subject calls for increased contact with the phenomena of science. The curriculum is built around demonstrations and laboratory work in spite of the difficulty in documenting the need for such student interaction (Brown, 1958; Nedelsky, 1958). Results in course examinations of students who have had laboratory sections are not significantly different from the results of those who have not had the experience. On the other hand, the difference in performance of boys and girls in physics is often attributed to the fact that the males are much more likely to have had the experience of manipulating erector sets, radio kits, tools, and other elements which give them experience related to the subject matter of physics. Stendler (1961) gives evidence supporting the above statement from a study of freshmen at the University of Illinois. Bruner (1960) says, "The second type of teaching aid has a function of helping the student to grasp the underlying structure of phenomenon--to sense the genotype behind the phenotype, to use terms from genetics. The well wrought laboratory experiment or demonstration is the classic aid in such activity" (p.81). Further on he says, "Models, such as a model of the molecule or an idealized model of the respiratory system, serve a comparable function" (p. 82).

On the other hand, Sanborn Brown (1958) says, "An extensive study was made to determine the effect of high school laboratory courses on freshmen laboratory performance at MIT. Almost no significant effect was measured. It was concluded that the intellectual stimulation of laboratory education at the high school level is its basic contribution"(p.334). Clearly, in this case, it would be difficult specifying the behavioral results of working with the materials of the subject of physics.

To repeat, in spite of this difficulty, the need for demonstrations and laboratory exercises is almost universally acclaimed by the scientific community. Perhaps the need is obvious, but the manner of presentation and the time in the education sequence at which the exercises are presented is at fault. In Bruner's book (1960), Inhelder is quoted:

> In view of all this it seems highly arbitrary and very likely incorrect to delay the teaching, for example, of Euclidian or metric geometry until the end of the primary grades, particularly when projective geometry has not been given earlier. So too with the teaching of physics, which has much in it that can be profitably taught at an inductive or intuitive level much earlier. Basic notions in these fields are perfectly accessible to children of seven to ten years of age, provided that they are divorced from their mathematical expression and studied through materials that the child can handle himself (p.43).

One small piece of experimental evidence exists that may be used to show that the fault lies not with the laboratory work but with the way in which the laboratory work is conducted. Wall, Kruglak, and Trainor (1951) have shown that performance tests in laboratory work increase the effectiveness of the laboratory exercise. In the performance test the student had to make responses using the equipment without the step-by-step prescription that usually accompanies a student laboratory period. The Wall study will be used later in this chapter to support the contention that if the type of student response were altered, the educational value of experience with phenomena of science would show a more positive correlation with academic achievement.

Before an attempt is made to resurrect the value of student interaction with the phenomena of science in the student subject matter interface, it is worth quoting the most direct statement of the situation confronting the science educator. Nedelsky (1958) says, "There is little empirical evidence that laboratory instruction in elementary courses contributes significantly to the student's understanding of physics. In the absence of such evidence, physics teachers argue a priori that contact with phenomena is a necessary constituent of adequate training in physics" (p. 51).

To summarize, Inhelder argues--and Stendler's results support the idea--that the important age for providing experience in manipulating the phenomena of the physical world is prior to high school. Brown and others have shown that laboratory work at or above the high school level bears little academic fruit in terms of enhanced ability when compared to students who have not had the laboratory experience. Trainor et. al. have shown that perhaps the manner in which laboratory courses are conducted is seriously at fault. The quotations of Bruner and Nedelsky were offered as samples of the universal insistence that in spite of the lack of evidence that they do any good, demonstrations and laboratory work are essential. In order to reconcile the strength of the belief in the need for laboratory work and demonstrations with the lack of evidence that these activities help the student attain the goals of instruction, the following argument is offered:

1. Student response is either not elicited or is in a form which diminishes the learning value of the exercise (e.g. cookbook laboratory forms). This follows from the passive nature of the student's participation in the classroom demonstration and the results of Trainor et. al. that performance tests in which the student must respond without a step-by-step procedural outline do enhance the value of laboratory exercises. Many studies and the words of many educators have pointed to the need for an appropriate student response to a stimulus if effective learning can take place. Out of the vast number of responses which a student may make to a classroom demonstration or to a laboratory exercise, some means must be provided for encouraging an appropriate response, noting which responses are made, and reinforcing preferred responses. Though many responses may be correct, it seems clear that merely sitting before many responses may be correct, it seems clear that merely sitting before a demonstration or filling in the blanks of a laboratory sheet are not the behavioral outcomes being sought--especially when the procedure is outlined step by step and the desired numerical outcome is well known in advance.

2. The length of time involved in dealing with a single concept in conventional laboratory work is so long that the learning efficiency of laboratory work is low. There is a delay between behavior and its consequences which is not reinforcing. In order to demonstrate a concept of importance to science, fairly sophisticated equipment is required even at the elementary laboratory level. Too often, emphasis is placed

upon setting up this equipment as a desirable end in itself. Setting up equipment may indeed be a desirable skill, but often almost the entire laboratory period is consumed in this activity and the important concept being demonstrated is lost in a rush at the end of the period. As a result, any insights or understandings gained in the exercise go not only unreinforced; they go unattended. Since the beginning student cannot always appreciate which observations are important and which are trivial, immediacy of reinforcement becomes an important tool in beginning learning. As the student becomes more sophisticated in a subject, he can formulate rules for determining the significance and correctness of an observation.

3. The laboratory and demonstration material is not being given to the student at the stage (elementary grades) in the student's development when it can do the most good in structuring the world for future learning. This follows from the argument of Inhelder and the results of Stendler which show that early experience with physical phenomena do result in enhanced academic performance in later years.

Lack of Consensus in the Elementary Curriculum. Except for nature study, health, and incidental work, such as accompanied the advent of the satellites and rockets, it seems safe to say that there has been no standard curriculum for science in the elementary grades. Recently educators and scientists have begun to address the problem (Karplus, 1962; Rosenbloom, 1964; Seeger, 1959; Stahl, 1961; Pennsylvania Curriculum Development Program, 1963; AAAS, 1963). Consistent with the scope of present-day science, these experimental programs cover a wide range of subject matter, and no hint of

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consensus of educators has yet become apparent. Many educators still feel that formal science instruction in the traditional areas of physics, chemistry, biology, and geology should not begin until high school or perhaps even college. The argument then runs that it is important to develop the processes involved in scientific inquiry at the elementary level rather than any particular content area. Exemplifying this point of view is the AAAS series of science activities called Science, A Process Approach. While there are those who oppose this point of view on the basis that is the student is taught the content his "natural powers of generalization" will enable him to use that content for the solution of problems, the inability to find an agreed-upon content has led to consideration of the behaviors which the elementary school student might learn in a program dealing with any science, be it astronomy, chemistry, biology, geology, or physics. The AAAS report (1963) considers the following to be the processes of science: observation, classification, recognition and use of space/time relations, recognition and use of numbers and number relations, measurement, communication, inference, and prediction.

It is noted that these processes cannot be taught without content, but the content is chosen more for its suitability in illustrating the process involved rather than for the importance of the content in the elementary curriculum. Nevertheless, an amazing amount of content in the AAAS series is apparently chosen to provide the student with the means of making the abstractions, visualizations, and generalizations which must be made when the student encounters a textbook presentation of science.

Behaviors Relevant to the Study of Science. For the purposes of this report a sequence of behaviors has been formulated which attempts to take into account the entering behavior of an elementary school student and which is sequential in that it builds toward ever more complicated and sophisticated behavior. The examples are deliberately scattered over the sciences in order to emphasize the fact that the instructional goals listed are intended to be applied to many areas of science:

1. The student should be able to make elementary discriminations in his environment and record these observations in his own words.

   Example: Green plants turn brown when deprived of water.

2. The student should learn to make quantitative measurements on his environment and record the results of his measurements in some orderly fashion.

   Example: Daily outdoor air temperature variation over the school year.

3. The student should learn to use instruments to extend his ability to observe and measure.

   Example: The use of the microscope to observe the living cell.

4. The student should learn to (a) determine the relationships between his observations and measurements and (b) use these relationships to solve a particular problem.

Example: The use of a measuring cylinder to determine whether liquid in containers of different shapes have the same volume.

Instruction in more advanced phases of a subject is implied in goals 5 and 6 which follow.

5. The student should learn the content of the scientific disciplines, and they should learn that this knowledge enables a new range of problems to be solved.

   Example: The relation between color and temperature to determine the temperature of an incandescent body.

6. The student should learn that mathematics must be applied to reduce difficult or complex problems to manageable form.

   Example: The use of the relation for centripetal acceleration to determine the orbital velocity of a satellite.

Interface to Provide Automated Science Presentation. It is the contention of this report that special need of elementary science instruction is interaction with the phenomena of the real (i.e. non-representational) world. What emerges is the need for an interface which can be used for automated science demonstration which involves student manipulation of the variables in the demonstration. For example, a lesson in electric currents should have a rheostat knob which enables the student to vary the current according to instructions. If an audio oscillator is part of the interface, there should be a control dial available to the student so that the frequency and intensity of the sound can be varied by the student as part of the lesson sequence. If the student is to observe the effects of temperature upon biological activity of a one-celled animal, the temperature control thermostat might be controlled by the student.

Subsequent displays should be contingent upon the student responses. Thus, if a student gives a response showing that he believes ice is a liquid, a branch sequence would be available developing the properties of solids, liquids and gases through manipulation of actual materials in the three states.

In an interface for elementary science education, many technological devices may be used which are also required for instruction in reading and mathematics. These include visual display devices such as film projection, video display, or an oscilloscope system. Often the visual display and the sound display systems can be used for the presentation of certain phenomena such as the interference effects of electromagnetic radiation upon television reception.

If the instructional goals listed above are considered, the criterion which emerges is that the interface must be equipped to enable the student to experience a wide range of scientific phenomena which can be put into or simulated in a small space. If a specific lesson in physics, biology, etc. is considered, then a particular facility may be desirable. If some concept such as relativity is deemed critical, then a special purpose interface can be designed to enable the student to evolve the laws of relativistic motion through simulation of a world in which the speed of light is 10 miles an hour. In such a world, which might be simulated as a flight trainer simulates flight, as the speed of 10 miles per hour is approached, the surrounding terrain would be foreshortened, particles encountered would have greater and greater mass, and oncoming light would appear to be more and more blue.

The stimulus and response requirements of science seem to fall into two areas. In one area the need for laboratory manipulative experiences is so great, or the degree of simulation of experience is so complex, that a device designed to meet the requirements is highly specialized and unsuitable for use outside of a limited area of instruction. The device needed will be called a special purpose device for science instruction. An example of a special purpose interface is provided by the lesson on force in the appendix of this report. The other area of science instruction has stimulus and responses requirements which can be met by commonly available stimulus and response devices; these will be called general purpose interface devices for science instruction. Thus a more or less special interface would be required for an undetermined fraction of all the desirable experiences in science. For the remainder of the experiences there would be sufficient versatility in the technological devices already present in the interface for reading and mathematics; and there would be sufficient degree of simulation and description based upon the student's prior experiences to enable a general purpose interface to carry the teaching load with perhaps minor modifications.

If the process approach is accepted, it is postulated that an interface design using standard technical equipment would provide ample opportunities for interface instruction which develops the abilities described above. With minor modifications the sound facility can provide a range of experiments in sound at the elementary level. The visual display can do the same for light. If an oscilloscope or television screen is part of the interface, it can be used to supply a visual display of sound phenomena; it can be used for programs in electricity and electronics and magnetism; and it can be used as a simulator of experiences, such as observation through a microscope, which normally involve only the sense of sight. Consider for concreteness a short example for each instructional goal listed above.

1. Elementary discrimination. When an intense visual projection is removed from the screen, a negative afterimage is seen.
2. Elementary quantitative measurements and record. Reaction time of each child in class detected by touch-sensitive screen after sound or sight signal.
3. Use of instruments to extend observations. Use of voltmeter to observe filament voltage.
4. Relation between observation and measurements and use to solve a problem. The problem may be the decrease in visual intensity of a TV screen as a knob is turned. The sensory observation is the decrease in visual intensity. The quantitative measurement is the filament voltage as displayed by a voltmeter. The (limited) solution to the problem is that the filament requires a minimum voltage to operate properly.
5. Relation between content and depth of solution to problems. If the student has learned about thermionic emission, he can infer that as the voltage is decreased the current through the filament is decreased and the current is no longer able to heat the filament sufficiently to cause an ample supply of electrons to be emitted.
6. Use of mathematics to handle difficult problems. If the student can perform the operation of squaring a distance and inverting the result, an oscilloscope screen or a TV screen in combination with a light of variable intensity could be used to enable the student to develop the inverse law of radiation intensity.

The installation of the meters and the control knobs is a trivial modification of any equipment which has a television or oscilloscope display.

If these are not part of the equipment, a different set of phenomena could be displayed. Furthermore, with the above equipment many other parallel experiences could be provided.

Summary. The history of elementary school science is too short and the subject matter is too varied to permit a listing here of curriculum areas relevant to an interface design. It is suggested that experiences with the phenomena of the natural sciences are important at an early age. An important reduction of the problem is possible if it is agreed that the development of a certain behavioral process in some areas of science are more important as an instructional goal than the study of any particular topic in science. This may be generally true even if certain specific topics turn out to be important enough to warrant universal inclusion in the elementary curriculum.

The implications for an interface design are that at the elementary level only a few special interface devices will warrent development--possibly for such topics as force, mass, and growing biological samples. For the development of behavioral goals which are related to all areas of science it seems that any general purpose advanced interface having such components as light pens, touch-sensitive screens, oscilloscope displays, slide projectors, and tape recorders will have sufficient flexibility to enable phenomena displays to be presented and to be manipulated by the student either in the manner of a simulation flight trainer or by the student operating directly on the physical variables of the display.

Summary of Subject Matter Implications for an Interface

The subject matter of reading, science, and mathematics for the elementary grades has been considered in order to extract the stimulus and response provisions which must be provided for an instructional environment in each of these subjects.

Mathematics. The analysis of the elementary mathematics leads to the conclusion that visual display with the use of auditory stimuli for special purposes and for students who cannot read will handle most of the problems of instruction in mathematics. However, two major problems of instruction may require additional display modes. The first of these is the abstraction of the concept of number from arrays of objects. If the student has already established the use of pictures to represent objects, pictures of arrays of objects will suffice for instruction leading to the concept of numerosity. If this ability to use pictures is not well developed, successful instruction may depend upon the use of real objects to develop the concept of number and attaching a verbal response to problems involving number. Once this has been accomplished much instruction in mathematics can proceed by developing verbal-symbolic correspondences as in reading and by developing the properties of numbers according to the place value schemes.

The visual-auditory combination may fail when the student must make visualizations in three dimensions from a two-dimensional display using algebraic relationships. For example, a student must be able to make responses depending upon the relation that $x^2 + y^2 + z^2 = c^2$ represents a sphere. In two dimensions he can be shown that $x^2 + y^2 = c^2$ represents a circle and it is not too difficult to extend this relation to a sphere. Other relations between numbers and space are not so easily extended from the two-dimensional case to the three-dimensional case. For example, the use of altitudes, slopes and contour lines to describe the terrain of a map probably requires some specific experience with the three-dimensional terrain or a raised relief map in order to develop the ability to visualize the three-dimensional terrain from a two-dimensional map with contour lines. The use of two-dimensional graphs or maps, the use of purely symbolic description of a three-dimensional surface--if they can be taught in the elementary program,--would be an important prelude to the use of symbolic representations of many-dimensional space (as in statistical mechanics and relativity) as a generalization from three-dimensional space.

Reading. In the conventional instruction program, much of the entering behavior of a normal six year old in our society is assumed for the purposes of instruction. Colors are assumed to be known. Common items are assumed to be familiar enough to be represented by pictures. In general, the speaking vocabulary is held to be sufficiently advanced so that instructions such as, "Put an X over the dog," can be understood. For this entering behavior, a program with auditory and visual stimuli is sufficient for establishing the grapheme-phoneme correspondence which our review identified as an essential part of reading instruction. At an earlier age, the child's visual discrimination is not nearly as well developed as required by the reading readiness tests which are often given. In order to attack the problem of establishing the visual discrimination of the graphemes which is required, it may be found that multi-sensory stimulus will be necessary. Thus, textured letters, jigsaw puzzle letters, three-dimensional letters which can be held and played with, may be necessary for reading instruction. On the other hand, all that may be needed is clever programs which develop the visual discrimination through reinforcement of steps toward the correct visual discrimination.

Science. An attempt has been made to show that science requires special purpose devices which provide the stimulus and response displays for perhaps a single concept (e.g. mass) and more general purpose devices which can teach the content of an area of science through a combination of flexible manipulative devices such as audio oscillators, meters, and projection lamps, as well as more conventional display devices. By conventional displays is meant the projection of pictures, symbols, and auditory verbal information. A great deal may be accomplished through simulation in which a display simulates an environment in only some of the aspects of the real environment. An example was suggested of a simulator which could display the effects of relativity. The response provisions of a simulated environment can be purely electronic so that a wide range of physical phenomena can be simulated. In the simulated presentation of physical phenomena, many sensory experiences will be omitted (smells, unexpected sparks, the flavor of chemicals in one's mouth, the sensation of heat and cold and other aspects of the sense of touch). It is not clear to what extent these omissions will interfere with learning. It may well be that the simulated experiences in combination with experiences outside of the formal learning environment will provide all the information for effective generalization and concept formation.

Instructional Environment Requirements. Table 1.1 compares the stimulus and response requirements of all three subject areas. The headings used are: (1) visual stimulus, (2) auditory stimulus, (3) tactile stimulus, (4) visual display for response, (5) auditory response detection, (6) object display and manipulation detection, (7) symbol and figure construction,,(8) sequential stimuli, (9) time factor presentation. In order to fit the requirements into tabular form, some of the descriptions may be cryptic. A more detailed discussion of each of the environmental requirements can be found in the previous sections discussing the subject areas.

TABLE 1.1. Stimulus and Response Requirements for the Instructional Environment in Elementary Mathematics, Reading, and Science.

	MATHEMATICS	READING	SCIENCE
Visual Stimulus	Numerals Symbols Drawings Pictures Words Objects Meaningful arrays	Pictures Symbols Letters Words	Natural phenomena Pictures and drawings Simulation pictures
Auditory Stimulus	Sound patterns Words (for young students)	Words Sounds for symbols	Sound phenomena
Tactile Stimulus	Objects for manipulation	Letters (for young students)	Natural phenomena-friction, heat, texture, etc.
Visual Display for Response	Numerals Figures Symbols Objects Letters and words Sequential choice display	Letters Pictures Words	Manipulative controls Sequential choice display
Auditory Response Detection	Words (for young students)	Phonemes Words Names of letters Words in context	Words (for young young students)
Object Display and Manipulation	Numbers of objects Patterns of objects	Letters as objects (for young students)	Models and objects of science area
Symbol and figure construction	Geometric figures		Graph construction Figure construction
Sequential Stimuli	Algorithm problems	Reading in context	Cycles Natural sequences Laboratory sequences
Time Factor Presentation	Patterns in time	Introduction of prompts with delayed response	Time factor in natural phenomena

Part B

Interface Aspects and Instructional Requirements

Illustrative Instructional Procedures

The concern of the first portion of this chapter has been how subject matter properties influence an instructional interface. A further concern is the implementation of instructional procedures that can be provided by a flexible (computor based) interface. To pursue this latter aspect, procedures that have been described in developing sequences in programmed instruction are discussed for illustrative purposes. The procedures considered are:

1. Determination of entering behavior.
2. Participation in terminal behavior.
3. Generalization display.
4. Gradual progression.
5. Reinforcement.
6. Prompt guiding of learning.
7. Withdrawal of guidance.

Each of these will be briefly defined and then a sample lesson described. The above have been called procedures rather than principles to deliberately avoid the suggestion that they are all inclusive or that the relation of these techniques to the learning process is firmly established by research in a wide range of learning situations. With this qualification, the manner in which an interface can provide for each procedure can be discussed. The final decision as to how much prompting and what kinds of reinforcement are desirable under each learning situation must be determined by practical experience and instructional research involving examination of the results of instruction. Here it only will be shown that a flexible interface can effectively apply these procedures in a way that provides a rich learning environment. For this purpose the areas of reading, mathematics and science will be considered.

Determination of Entering Behavior. In a simple case this means the determination of what the student already knows about the material which will be taught in the program. In a more sophisticated case the entering behavior of the pupil may be used to prescribe a course which is designed for his individual interests and abilities. If his behavior can then be monitored during instruction, adjustments can be made on the basis of continually accumulating information as well as the entering behavior information. Entering behavior can be measured along many dimensions. A listing due to Travers (1954) follows: (1) the extent to which the individual has already acquired the responses to be learned in instruction;(2) the extent to which the individual has acquired responses which are necessary "prerequisites" for learning; (3) the extent to which the individual has acquired "learning sets" which facilitate what is to be learned; (4) the extent to which the individual has the ability to make the kinds of discrimination--e.g. spatial, abstract, numerical and linguistic--which are necessary to profit from instruction; and (5) the extent to which the individual has certain kinds of motivational and interest requirements as a result of his past history.

Participation in Terminal Behavior. This might be called "vicarious participation"; its purpose is to make certain responses more probable when they are required in the instructional program. The reinforcing property of terminal behavior competence may be useful in early instruction to reinforce student interest and to enhance motivation. In learning to ride a bicycle, for example, a good teacher often makes a point of letting the child ride the bicycle by himself during the first few lessons. In this case, by himself means that the teacher is holding up the bicycle from the rear. For the student, however, it is the terminal behavior he thought to engage in only after much practice. Being able to "ride a bicycle" just a few minutes after instruction has begun can be highly motivating and can provide a basis on which less dramatic behaviors can be built. After the initial riding experience, the child's feeling of excitement and accomplishment are likely to generalize to other components of the task. In the same way, it is motivating for a beginning typist to type 60 words per minute although it may be the same word typed over and over. At least some of the elements of an expert typist are involved and may seem very accomplished to the beginner. A simulated environment in which the student has the illusion of participation in the terminal behavior (diagnosing a disease, flying an airplane, solving a problem of scientific measurement) also appear to enable discrimination training to take place by providing appropriate contingencies for both right and wrong responses, without the disastrous consequences which might occur in a completely realistic situation.

Similar to a simulated experience in the terminal behavior is the experience of watching or participating in a story with desired elements of behavior integrated into the story. Thus, a story in which scientific analysis provides the solution to a desperate problem, e.g., the development of a vaccine, might serve to make responses displayed in the story (self-discipline, hard work, persistence in the face of failure, use of subject knowledge, safety precautions, etc.) more probable as the student proceeds through an instructional program. A relevant statement is made by Bruner (1960) in discussing aids to teaching.

> Closely related to these are what might be called dramatizing devices. The historical novel that is true in spirit to its subject, the nature film that dramatizes the struggle of a species in its habitat, the exemplification of an experiment executed by a dramatic personality... all these can have the dramatic effect of leading the student to identify more closely with a phenomenom or an idea. Undoubtedly, this "aid" in teaching can best be exemplified by the drama-creating personality of a teacher. But there are many additional dramatic aids upon which teachers can and do call--and one wonders whether they are called on enough (p.82).

Generalization and Discrimination (Concept Formation). Generalization refers to the fact that a student learns to respond to similar elements in different learning situations. He learns, for example, to recognize that all words with certain characteristics belong to one class called nouns, or that mammals belong to a class called vertebrates and many other creatures belong to a class called invertebrates. In addition to responding to similar elements in different situations, an individual also learns to make appropriately different responses to different stimulus situations. For example, he learns to discriminate between nouns and verbs. When a young child, on the right occasions, says dog and cat, he has learned to discriminate between these two classes of animals. When he calls a strange cat that he has never seen before by the right name, or when he says the word cat to the picture of a cat or to the sound of a cat purring, he has generalized within the class of stimuli that have to do with cats. When an individual has learned to make discriminations so that he can respond selectively to different stimuli, and when he has learned to generalize these same responses to a variety of situations, he has learned the concept. In the same way that the child learns the class concept cat and dog, the older child learns the class concepts noun and verb, and the still older child learns the concepts light and sound.

Consider a specific example from reading instruction. In order to identify a letter--even though the particular letter has never been seen before--the observer must be able to identify the letter by the elements which all letters have in common plus the elements which separate the letter in question from other symbols such as the rest of the alphabet, numerals, Greek letters, etc. In order to teach this ability, a wide variety of different forms of the same letter is reinforced. At the same time the limit of generalization or stimulus discrimination is trained by reinforcing responses to differences between stimuli which have common elements, i.e. At the same time that the student is learning that the letter F is printed in many ways, sizes, and colors, he must also learn that the letter E is not one of the ways of writing anF in spite of the common elements between an F and an E. To accomplish this, F.is presented at first with symbols that are quite different in shape, and gradually the student is brought to discriminate the F from similar letters such as E.

Gradual Progression. The principle involved here is that the program of instruction must progress gradually so as to minimize wrong responses which may then be difficult to extinguish. The integration of this principle with procedures for the use of errors as effective learning experiences appears to be the efficient course for an instructional progression. In general, however, to obtain a reasonable rate of progress toward an instructional goal, the material preceding a display must have the elements which will permit a fair and challenging chance to make correct responses. Classical or expected errors may then be dealt with by a branched set of items which are themselves arranged in a gradual progression toward an instructional goal. An aspect of a permitted error rate is that certain items can be used for diagnostic purposes. The quick student who masters these diagnostic questions proceeds through the program more quickly. The student who misses the diagnostic items is provided with the additional steps required for mastery.

Reinforcement. Certain stimuli contingent upon the occurrence of a response may make the response more likely to occur in the future. In the case of human learning, the determination of reinforcing stimuli is an important element in the development of an instructional interface. Reinforcers may be extrinsic (money, a gold star, approval) or intrinsic (related to subject matter attainments such as getting the correct answers, solving a challenging problem, developing increasing competence). In general, intrinsic reinforcers are preferred when they are effective, since extinction of responses may occur when extrinsic reinforcement is withheld. From the practical point of view it is efficient not to need a complicated system of awarding reinforcers. If extrinsic reinforcers are required, the interface can be programmed to award them on the appropriate schedule for the degree of persistence of response which is desired at a given learning stage. A major advantage of a flexible interface may be the provision of intrinsic subject matter reinforcements which result from the student's ability to freely manipulate and modify subject matter properties.

Prompting and the Guidance of Learning. There is discussion in the current literature of learning technology concerning the relative merits of various prompting procedures. In general, it seems clear that in many stages of instruction efficient learning requires a hint or guide to the appropriate response to be learned. Where possible, a prompt which can be used as a mediator in future learning is to be preferred to prompts which are unrelated to future tasks. For example, a picture of an apple is a prompt to the sound of a letter a and a phoneme for the letter a can become a prompt for response differentiation of the visually presented letter *a*. Depending upon the reading program both of the above prompts can be useful in future instruction sequences. On the other hand, an example of a prompt which may be unrelated to future learning in reading is the practice of putting significant letters (silent *e*, for example) in different colors from the other letters.

The interface environment can provide a wide range of prompts and procedures for guiding the learner. In reading, a word which a student finds difficult in pronouncing can be prompted by having the syllables spread apart on a screen, by having the word become larger in relation to the surrounding words, or by having a voice pronounce the first syllable. In mathematics, a numerical answer can be prompted by the appearance of a number of objects in a visual display, by a faint dotted outline of part of the numeral, or by the breaking down of a difficult problem into a more simple problem. For example, by the use of the distributive law and the idea that numbers have many names, the answer to the problem $7 \times 8 = 56$ can be prompted by the form:

$$7 \times (4 + 4) = (7 \times 4) + (7 \times 4) = ?. \quad (\text{Answer: } 28 + 28 = 56)$$

Withdrawal of Guidance. By the "fading of prompts" is meant the gradual elimination of a hint or cue which leads a student to the right answer. For example, if a house is built around the letter *H* as a prompt for the sound of *H*, the prompt may be faded in successive presentations by gradually eliminating parts of the drawing of the house until the student is able to respond when only the letter *H* remains. The need for guidance can be detected by the time it takes for the student to respond after the presentation of a stimulus. If a student is reading, a delay in pronouncing a word may indicate that he needs a prompt such as having the first letter or symbol pronounced. The latency of response is a guide to both the need for a prompt and the rate at which a prompt should be eliminated or faded. As the time between stimulus and correct response becomes shorter, the intensity of the prompt can be decreased until a quick response is available when no prompt is present. As this point is approached, the prompts such as those referred to in the preceding section on prompting can be gradually eliminated. The troublesome word becomes displayed almost identically with the rest of the text; the breakup of an arithmetic problem into simpler steps is only hinted at; the prompt for a numeral in a problem becomes barely visible.

2

Sample Lesson in Mathematics

Consider a lesson in extending the understanding of the number system from 20 - 99. A projected instructional interface for this lesson will be examined for the manner by which it can include procedures outlined above.

Extending Understanding of the Number System from 20 - 99. The terminal behavior being sought here is the ability to use the decimal number system in the range 0 to 100 in the following ways: (1) to be able to state X groups of ten is X.,e.g. Four groups of ten is 40. (2) If shown X groups of ten the student will say "X-ty." (3) If asked, "If you put one more group of ten with 40, you will have ______?" he will respond, "50." (4) If shown XY, the student can determine that this means X tens and Y ones.

Determination of Entering Behavior. The entering behavior required for this lesson is the ability to count to 100, the ability to group "things" into a group of ten, the ability to exchange ten objects for a ten-bar, (A ten-bar is a larger object used to represent ten things.) and the ability to represent the number property of one to nineteen objects by a numeral in the decimal system.

To determine whether the student can count to 100, the student is asked orally (or by a printed command if he can read) to count to 100. The appropriate response is either to select in sequence, by pushing elements of a visual display, the numerals from 1 to 100 or to say them aloud. (The entering behavior in terms of the ability to read and write then becomes the first part of any examination.)

To test the ability to group things into a group of ten, the student may be given a large supply of discs and be asked to place one group of ten upon a table. Assuming that the student has learned that a ten-bar represents ten objects and that he is familiar with the word "ten-bar", an instructional interface must have the following additional capabilities: dispenser to present the student with 10 discs or other objects, a sensing device to verify that 10 discs are before the student (a more advanced student could be instructed without the use of three-dimensional objects, e.g., moving figures on a screen or pictures of objects on a page. The possible instructional value of object manipulation for beginning students led to organizing the lesson in terms of the manipulation of real objects.), a supply of ten-bars, a means of determining that the 10 discs have been removed and that the ten-bar has replaced them.

To test the understanding of the numbers from 1 to 19, the student must be given the auditory or printed command, "Which picture has fourteen things?" or "Take fourteen discs and place them upon the table." or "Make fourteen by using a ten-bar and four discs." The response will then be detected by the selection of the correct picture or by the measurement of the objects which have been placed upon a surface.

Participation in Terminal Behavior. The student may be presented with arrays of objects, arrays of objects arranged in groups of ten, arrays of objects with a ten-bar for each group of ten. The student has a single choice control before him which may be called an activation button. If he activates the control, he is told something which will become part of his terminal behavior. For example, if there are seven ten-bars and three additional objects, when the control is activated the student is presented with either a visual display, 73, an auditory display, "seventy-three," an auditory display "seven tens and three ones," or the seven ten-bars disappear and are replaced by seven groups of ten discs. This presentation may take place as part of a story so the activation of the control comes in response to a question in the story such as "What number (numeral) do we write now?" The idea is that by talking to the student as if he is part of the story, he may identify himself with the operations which are being displayed each time he pushes the activation button. By being thanked by a character in the story for supplying a number he can imagine his participation in the terminal behavior. This technique requires a means of presenting a story, say on tape, which involves various number tasks and which can be stopped while awaiting student response..

Generalization Display. Numerals must be presented in various type styles, including handwritten symbols. Arrays of objects must use a wide variety of objects: discs, trucks, horses, men, dots. Arrays of objects must be displayed in various geometric arrangements: squares, triangles, random arrangements, three-dimensional arrays. Various kinds of grouping must be employed: fourteen may be displayed as ten grouped discs and four additional discs, one ten-bar and four additional discs, one ten-bar and four additional discs, fourteen neatly arranged discs and fourteen scattered discs. Various visual and auditory equivalent stimuli and response can be employed: the student can be asked, "Find fourteen things," "Find enough discs to make one ten and four ones," "Find enough red discs to match the number of black discs on the table." On the other hand, a similar variety of visual commands (sound command with visual display of numeral) may be given using the arabic numerals, the printed words for the numbers, or arrays of dots to represent a number of objects. Responses may be required for which the student supplies a numeral for a number of objects as well as a number of objects for a numeral.

Gradual Progression.

1. The student counts objects to 100 by ones. The various ways of printing the numerals (14, fourteen) is displayed, and the student's oral response for each number is monitored.
2. The student counts objects to 100 by ones. An array of dots is added to the display such that a dot appears for each object counted and the dots are grouped by tens each time an additional ten objects are counted. For example, if forty-three objects have been counted, the numeral 40 would appear under four groups of ten, and the numeral 3 would appear under the additional three dots.
3. The student counts arrays of dots or objects which are arranged in groups of ten. Thus, if he counts twenty-three objects, he is informed, "That's right. Twenty-three is two groups of ten and three more ones."
4. The student matches groups of ten.
5. The student is presented with an array of objects in groups of ten and determines how many groups of ten there are.
6. The student is presented with many groups of ten and circles a certain number of groups, as directed.
7. The student is given a number of objects and asked how many groups of ten he can make. Each of the steps 3-7 is initially a problem with exact multiples of ten and then with an additional number of ones, e.g.,

In (4) above the student is initially presented with arrays of objects which are multiples of ten and grouped by ten. He is then asked to find an array of dots which matches the array of objects. The next step presents extra objects so that the entire array is not a multiple of ten (say 4 groups of ten plus three--43) and the student is asked to find the array of dots which has the same number of groups of ten (four groups of ten dots). The student response may be either by multiple choice or by constructed response.

8. The student is shown the numeral 20 and told that the 2 tells the number of tens. He is asked to find the two tens in a multiple choice problem of arrays of dots.
9. The student finds the number of tens in an array when presented with only the numeral. "When you are shown this--30, find the box with the correct number of tens."
10. When shown a number of tens in array, the student selects the numeral which gives the correct number of tens.
11. Steps 8 through 10 are repeated with elements in the unit's place.

Reinforcement. On an appropriate schedule, reinforcement can be provided after certain responses by supplying particularly attractive and novel items for the object arrays of subsequent problems. Other appropriate reinforcements are: (1) the opportunity to play number games related to the lesson, (2) the awarding of attractive pictures illustrating some of the relationships which have been learned, (3) the opportunity to choose to skip a certain number of steps in the instructional process, and (4) extrinsic praise and symbols of achievement.

Prompting. Overt instructions may be provided which do not supply the answer. For example, if the student must group objects by ten, he can be asked, "Can you make one group of ten? ... Now can you make another group?" The key to the need for such prompts is the student's activity or lack of it. Where a visual display is to be selected as a response, the intensity of presentation can be altered to make the correct element more likely to be chosen by the student. In rare instances the correct response to a projected problem can be presented in a prior statement, i.e. The student can be informed that 25 represents two tens and five ones prior to a problem in which two groups of ten objects and five additional objects is intended to call forth the response 25. (This type of prompt must be used with discretion because some students will pick up the ability to use the cue without an analysis of the problem.) In problems for which the student must arrange groups of objects, a visual array can be presented as a prompt.

Even if the student copies the visual array he is making the proper discrimination in order to make his response. Of course, this type of matching practice is part of the program at an earlier stage but can be used as a prompt for a latter part of the program.

Withdrawal of Guidance. The prompts described above help the student to understand what kind of response is required and make the correct response. As soon as the student becomes familiar with the kinds of responses required, the prompts which assist him to make groups of ten can be withdrawn. The prompts, such as a visual array to assist the student in counting out groups of objects, which help the student to make the correct response are used in the early stages when there is a high probability of error. As soon as the latency of response is short or the frequency of error is low, such cues to the correct answer can be used only when the student fails to respond within a certain period of time or when the student makes an error. In the latter case, the use of a prompt after an error may have value as an overt correction of an incorrect response. The intensity of a visual array of dots which is being used as a prompt can be controlled in relation to the student's latency of response and error rate. An alternative for the arithmetic program is to display the number of dots or the number of groups of the student's answer when the student's answer is incorrect. For example, if the student is to make four groups of ten objects and he makes five groups of ten, five groups of ten dots might appear in red while four groups of ten appear in black so that the student can compare and realize that his response was incorrect.

Summary

The consideration of instructional procedures leads to additional stimulus and response requirements for the instructional environment. These additional requirements are: (1) the detection of student behavior--such as vocabulary used, number usage in play, preference for certain activities, (2) the presentation of a simulated or controlled experience which enables the student to participate in the terminal behavior being sought, (3) the presentation of a wide variety of stimuli for a concept which must be generalized and the presentation of stimuli which define the limits of acceptable generalization, (4) the presentation of stimuli in either a progression which is known to be effective in leading the student to the terminal behavior or in a progression which has branch points for anticipated student problems, (5) the occurrence of reinforcing stimuli, (6) the presentation of guiding stimuli, and (7) the provision for withdrawing the guiding stimuli.

Part C

Possibilities of a General Purpose Student-Subject Matter Interface

This section will consider the similarities among subject areas which may make feasible a single instructional interface which can be used to teach in such different subject areas as mathematics, reading and science. The differences among subject areas which will necessitate special interface devices will also be discussed. The basis for the conclusions is the analysis drawn from this chapter. From the stimulus and response requirements of the subject matter (Part A) and of the instructional procedures (Part B) a judgment can be made as to the properties of a single instructional device which could be used for instruction in subjects which seem to have little in common. This judgment is influenced by what seems to be technologically reasonable, but no attempt has been made to restrict the ideas to the hardware currently available.

Basis for Estimating Subject Matter Range of General Purpose Interface

Even if the environment presented only visual stimuli, much as a book does, the logic which unites the stimulus to the student's response would put the device into a different class from books with paper and pencil responses. Thus, it is meaningful to ask what is the range of applicability of an interface with given stimulus and response provisions. For example, with only visual stimuli and a general purpose keyboard for responses, instruction may be provided for all students with a certain entering behavior (not necessarily ability to read) in such widely diverse areas as reading instruction, mathematics, science, as well, as subjects such as history, literature, art, engineering calculations, and experimental techniques in science.

It is clear that sometimes a visual display with a touch-sensitive response display will not suffice. Three dimensions of the problem seem to be of major importance:

1. The entering behavior of the student determines many of the stimulus and response characteristics which an interface must have in order to provide instruction. For example, a visual display of magnetic experiments may be meaningless to a young student who has never experienced the

ways an actual magnet interacts with magnetic and non-magnetic materials. However, the example requires some elaboration since a student with a history of experience in related areas could be instructed in magnetism by a visual display alone. At this point the question of instructional efficiency enters. Efficiency is here defined as instructional time to terminal behavior for students who begin instruction with equal entering behavior and equal abilities. Thus, while almost any predominantly intellectual subject may be taught with purely visual displays, the end result may be accomplished much more quickly and easily with appropriate displays and manipulative features other than visual ones. In general, but not always, the less advanced a student is in a subject, the greater will be the need to utilize a wide range of display and response modes.

2. The subject matter determines other stimulus and response characteristics which the interface must have. While many things about violin playing may be taught by visual display with keyboard responses, most of the instructional time must be employed developing the psycho-motor skills required. Thus, either a violin or elements which develop the skills of violin playing would be required as part of an instructional environment. Thus, the extent to which the subject matter requires a combination of sensory and motor responses is the second dimension of analysis for the determination of the stimulus and response provisions of a general purpose interface.

3. The instructional requirements for effective learning will influence the stimulus and response provisions of the interface. If guidance is needed to teach a certain response, the stimuli to provide that guidance will have to be incorporated into the interface design. For example, if the student is to select a letter from an array of letters, and good instructional practice indicates that the letter to be chosen should be made more prominent during the initial stages of instruction, a means of backlighting the letter may be incorporated into equipment design.

Heirarchy of Stimulus and Response Provisions

Visual and auditory display systems clearly rank highest for the purpose of a general purpose interface. In addition to the straightforward matter of presenting pictures and verbal information, each of these two display provisions can be used to present information ranging over a tremendous range of subject matter and student entering behavior. Time can be introduced through pulsed sound and visual display. Analogies can be developed through animation. Simulation can be developed through response of the display to the student behavior. Aspects of science can be developed not only through the display, but through the inherent technological elements of the display, e.g., A magnet brought close to an amplifier tube will change the level of sound and illustrate an item of instruction relating to the gain of a vacuum tube. Through polarized light displays or two color display, depth can be simulated. Physiological phenomena involving sensory perception can be illustrated along dimensions of pitch, flashing light frequency, optical illusion, fatigue, attention, stimulus intensity, etc. Almost all subjects have been attacked at some level by audio-visual instruction methods. The addition of logic between the stimulus and the student response so that further displays are contingent upon the student responses will greatly enhance the instructional possibilities of an interface with auditory and visual displays only. For example, an audio-visual film can demonstrate the mixing of two frequencies to give beats. An interface can provide for manipulation of frequencies by the student so that he must choose the appropriate frequencies to obtain a given beat frequency. Failure to accomplish this task would lead to remedial displays.

Response Elements for a General Purpose Interface

The most flexible response facility envisioned as a result of the stimulus and response analysis made here is a touch-sensitive display. By this is meant an array of elements such that a wide variety of symbols can be projected upon the elements. When a symbol is touched, environmental changes occur which are controlled by the logic circuits of the device. A response element might have a color, a letter, a number, a mathematical symbol, an electronic symbol or a picture projected upon it. In many cases the response elements may also serve as the visual stimulus for the student. Response would usually be made by touching an element, but other means of activation, such as light pen, are feasible. Thus, a touch-sensitive display can provide for multiple choice responses, discrimination responses, constructed verbal responses, solution of number problems, or manipulation of the original stimulus display according to some rules. For example, an element held down could change the intensity of the visual display or its color proportions. Alternatively, an element could change a frequency of an auditory tone as long as it is touched. The limitations of the use of the touch-sensitive response display would seem to lie in the student's ability to be instructed in its use and the limitations of time; i.e. it may take so long to generate certain responses by a touch-sensitive display that instruction/ may become uncertain. For example, a touch-sensitive display with discrete elements might be an awkward means for drawing a smooth curve. On the other hand, the ability to change the symbol in an element by a switch may reduce the time to form an answer. For example, if the symbols can be changed from letters to arithmetic numerals, the fact that a touch-sensitive display is used may make the generation of responses to arithmetic problems easier than would be the case for hand-written responses.

Limits of a General Purpose Instructional Environment

To be considered are the aspects of mathematics, reading, and science which require special purpose instructional devices.

Mathematics. The limit of the general purpose instructional environment depends upon the extent to which the student should manipulate objects to develop mathematical principles. The student may make an array of 3 x 4 and 4 x 3 objects to illustrate the commutativity of multiplication. This principle may be taught equally well by manipulating sets of objects on a screen with a light pen or by making arrays of pictures light up on a touch-sensitive display.

In another problem the student identifies geometric objects such as cubes, cylinders, spheres, and cones. At some stage of education it may be important to use the actual three-dimensional objects for instruction and an attempt to make a lesson conform to the format of a touch-sensitive display may result in an awkward sequence. For students with a different history, a touch-sensitive display using realistic photographs of these objects may be sufficient.

Finally, the various branches of geometry require line drawings to be constructed by the student, e.g., bisect the angle using your compass and straightedge. The technological means of providing this facility in a general purpose interface is not clear. Thus, the use of a hand tablet or some other device which would permit the student to make the line drawings would seem to fall into the class of special purpose devices.

Reading. The general purpose environment outlined in this section would not have the means of detecting the responses in oral reading. In the early stages of reading instruction, oral responses must be detected and compared to the printed words that the student is reading. For this purpose the ability to detect a limited vocabulary of oral responses as made by a particular student is required. Thus, if a program cannot be devised which does not circumvent the need for detecting oral responses, either human instruction or a special device to detect oral responses would be required.

Science. The limits of the general purpose interface in the area of science depends upon the extent to which simulation and verbal instruction using pictures and line drawings can substitute for experiences with the actual phenomena. For example, it is not clear whether the concept of mass can be taught to a young student without the use of experiments with objects of varying mass, but the importance of having the experience occur during the lesson may justify the creation of special devices to teach certain basic concepts in science through the manipulation of a restricted range of phenomena.

In summary, an interface which supplies visual and auditory stimuli of the conventional audio-visual type (slides, tapes, video-tape, motion pictures or other) united by logic circuits to response provisions of a touch-sensitive display will serve to teach a wide range of students in a wide range of subjects. Flexibility can be accomplished by storing display elements by some means and altering the displays for different areas of instruction. However, each subject area will have some desirable lessons which cannot be taught effectively by the general purpose interface and which will require special stimulus and response provisions.

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CHAPTER III

INTERFACE EQUIPMENT CONSIDERATIONS

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Preface

This chapter will concern itself with visual and auditory information input channels, response output and the technology available for using these capabilities. Physiological and human factor considerations are briefly reviewed, but the emphasis is on the techniques available for utilizing these human capabilities in the educational environment. The scope of coverage is intended to include presently available devices, technically feasible devices, and potentially available devices. Some devices in the latter two categories may be financially impractical, but are included for research considerations and their possible long-range applications.

Cost and availability data have not generally been included because of the dependence of such information on quantity and market considerations when equipment is commercially available. Also, much of the equipment discussed is of a prototype nature and cost data is usually not known and cannot be accurately estimated. Specific sources of supply are mentioned only in those cases where the designation of the manufacturer aids in describing the equipment or otherwise serves as a reference to more information. In general, the bibliography serves as the directory to further exploration of any particular item discussed. The discussion of equipment in this section is not intended to be exhaustive or to serve as a listing of available equipment, but rather to indicate the possibilities that exist and the development work in progress that can contribute to the implementation of an experimental, and eventually operational, educational environment.

Part A

Visual Communication

The visual channel has the inherent capability of the highest information rate and the greatest pattern variation of all available human communication channels. It has been estimated (Jacobson, 1951) that each eye has an information bit rate in excess of 4×10^6 bits per second and although much of this information is processed before reaching the brain, the eye can make available very large amounts of information to be processed and interpreted. With each optic nerve containing a million or more individual fibers, it is possible to conceive of 2^{10^6}(roughly $10^{300,000}$) different message units or patterns capable of being transmitted. (To appreciate the size of this number, it has been pointed out that only about 10^{54} neurons could be packed into a cubic light year.) This is a much greater amount of information than can be utilized by the brain and in those cases where a visual display presents an excessive amount of data the observer tends to abstract those features which represent redundant groups of data. The resulting perception thus contains a comparatively small amount of information, but it retains the essential character or "meaning" by eliminating most of the redundancy. Parameters abstracted are properties such as form, color, location, symmetry and many others. The significance of such abstraction of information to an information display device is that beyond some limit little or no additional information is transferred with increased information capacity of the display. The human is reported (Quastler, 1956) to have an information processing capability of the order of 25 to 30 bits per second, and where displays are used principally for displaying information for human processing, this limit may help specify the requirements of the display.

General Considerations

In order to meaningfully consider visual displays, the basic characteristics or capabilities of the visual channel (the eyes) might be briefly reviewed. These capabilities concern light, space, and time. The light capability of the eye includes both sensitivity and discrimination of brightness. The relationship between brightness of an object and its background is called brightness contrast and is expressed as a percentage by calculating $(\Delta B/B) \times 100$ where ΔB is brightness difference between object and background and B is background brightness. Contrasts of about 30:1 are preferable in black and white displays.

Spatial discrimination includes the four categories of visual acuity, depth discrimination, form discrimination, and movement discrimination. Visual acuity is a measure of the eye's ability to detect the smallest target. It is defined as the reciprocal of the just resolvable visual angle measured in minutes of arc. With light spectral energies in the photopic region (5000-6250 Angstroms) the visual acuity varies between 0.5 and 2.0 depending on illumination intensities (Shalaer, 1937). Visual detection, however, depends both on brightness level and contrast as shown in Figure 3.1. The curves labeled 1% to 100% are for targets that are either brighter or darker than their background. The curves for contrast above 100% are only for targets brighter than their backgrounds. The thresholds in the figure are for 99% probability of detection which is almost certain detection. Visual acuity as a function of brightness of task area and immediate surrounding area is illustrated in Figure 3.2. Depth discrimination

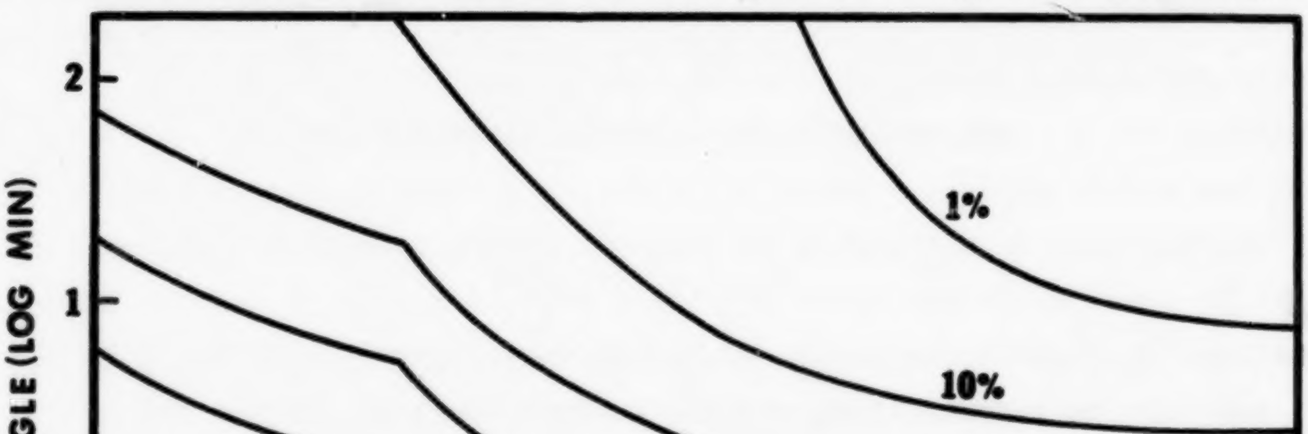

Fig. 3.1. Brightness Level and Contrast.
(Morgan et al, 1963, p. 60)

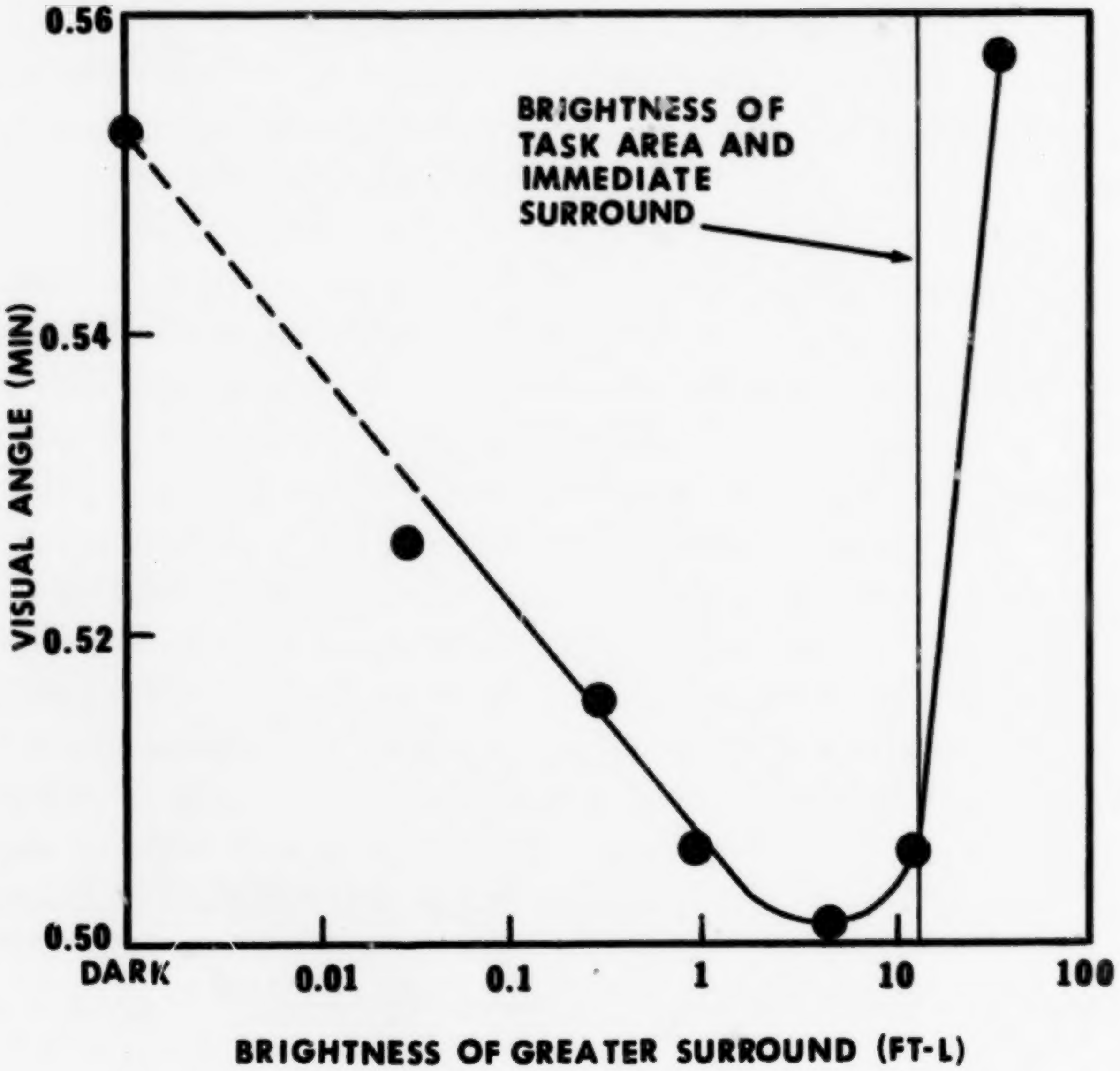

Fig. 3.2. Visual Acuity as Function of Brightness of Task Area. (Morgan et al, 1963, p.62)

makes use of many cues with the principal ones, at least for objects within 2500 feet, being those resulting from binocular vision such as muscle tension to accomplish focus. Form discrimination utilizes visual acuity together with stored information regarding form with the principal cues being boundaries and shape. Movement discrimination is defined as the slowest perceptible rate of movement of the stimulus.

The ability to discriminate time is limited by the response timelag of visual channel stimulation which varies from 0.05 to 0.4 seconds dependent upon color and intensity of stimulus. If a pulsing light is displayed with increasing pulse repetition rate, a point will be reached where the observed flicker disappears. This is often called the critical flicker frequency. Figure 3.3 illustrates the dependence

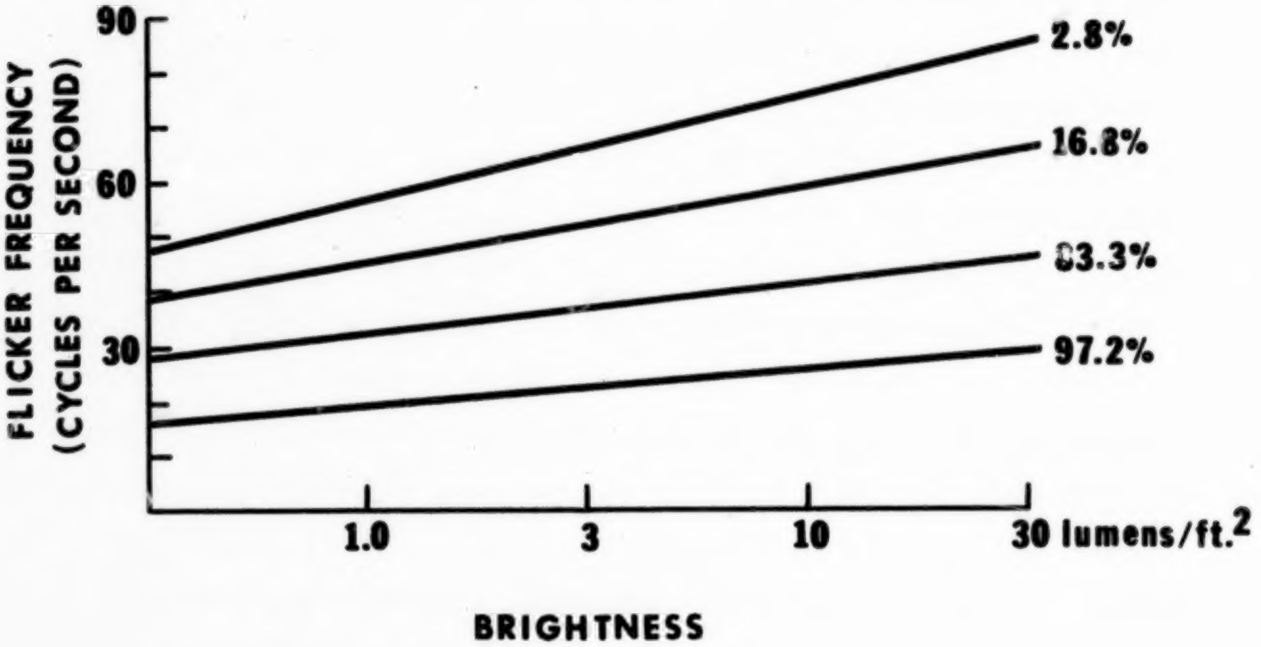

Fig. 3.3 Relation of the Threshold Frequency of Flicker to Brightness (Zworykin & Morton, 1954, p. 188)

of flicker threshold on brightness and duty cycle (percent of time light is on).

Other factors of significance to visual displays are display response times and display configuration. The response time is the time interval between the initiation of action to cause a display change and the actual change of display. This time can be a function of many factors such as queuing load on equipment involved, erase and write times of display used, and processing time required to create new display information.

The primary consideration of display configuration is size and shape. Experiment and moving-picture experience show that with a picture having a vertical to horizontal dimension ratio of around 3:4, the vertical dimension should not subtend a vertical angle of more than 15 degrees. Such an angle permits obtaining a more or less simultaneous impression of the entire content of the display and examining in detail all points simply with motion of the eyeballs and not the head. This is a ratio of picture distance to height of not less than about four. However, this is not a sharp optimum and reasonable variations are entirely acceptable.

Coded Displays

Perhaps the simplest displays from a control and implementation viewpoint are the coded displays such as lights, mechanical indicators, and keys. This type of device is completely adequate when messages of low information content are to be transmitted. For example, feedback information concerning correctness of a response is often of this nature and consists of one or two colored lights mounted on the response device. The code or "meaning" of displays of this type must be easily understood by a user and generally limit the amount of information such a device can display. Figure 3.4 illustrates the general shape of the curve which plots percent errors as a function of number of symbols or code complexity. There is no scale on either coordinate because exact metrics depend on type of code (color, shape, size) and the conditions under which it is used. However, the important thing about the curve is its general shape which indicates that severe penalties in accuracy are encountered when too much information is packed into such a display. A "rule-of-thumb" may be to use only as many symbols in a code as are absolutely necessary.

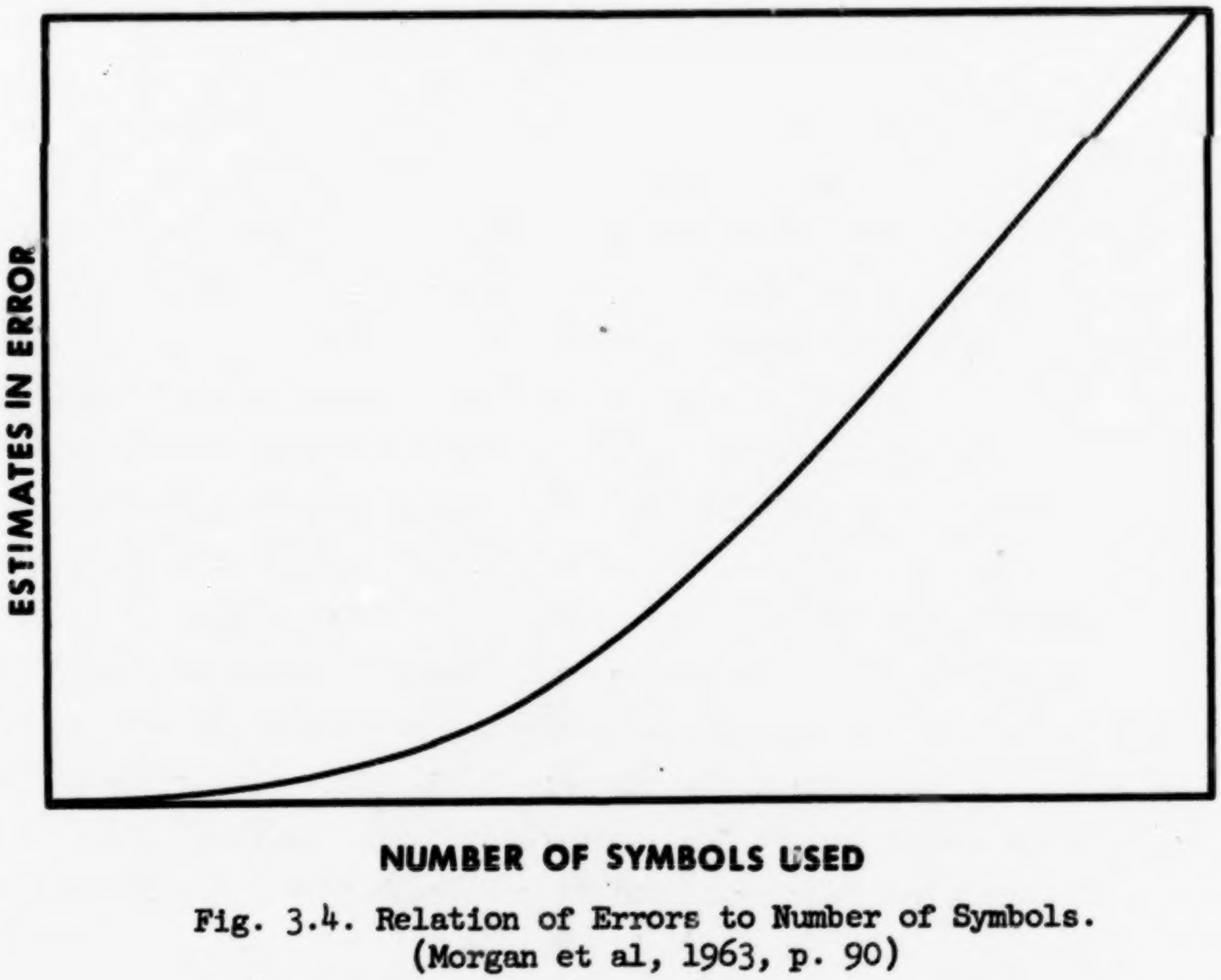

Fig. 3.4. Relation of Errors to Number of Symbols.
(Morgan et al, 1963, p. 90)

The most common codes used in devices of this type are obtained through the use of colors, shapes, or alphanumerics. With color codes the use of colored lights is usually preferred to paints or reflected colors since colored lights are not affected by the color of the general illumination as much as surface colors. A normal person can correctly identify around ten spectral colors when the brightness is one millilambert or more and the visual angle is 45 minutes or more. When shape coding is used, the shapes should generally have high association value with the subject matter or else be highly discriminable between shapes. About fifteen different shapes can be reliably distinguished when the outline is sharp, the contrast high, and the visual angle at least twelve minutes. When alphanumerics are used as with keyboards or for printed displays, they should have high contrast, sharp outlines and subtend a visual angle of at least ten minutes. In general, when using coding of the type discussed or of other types, care should be taken not to conflict with the rather universal associations some codes have acquired such as the color red implying danger or the symbol "+" meaning addition.

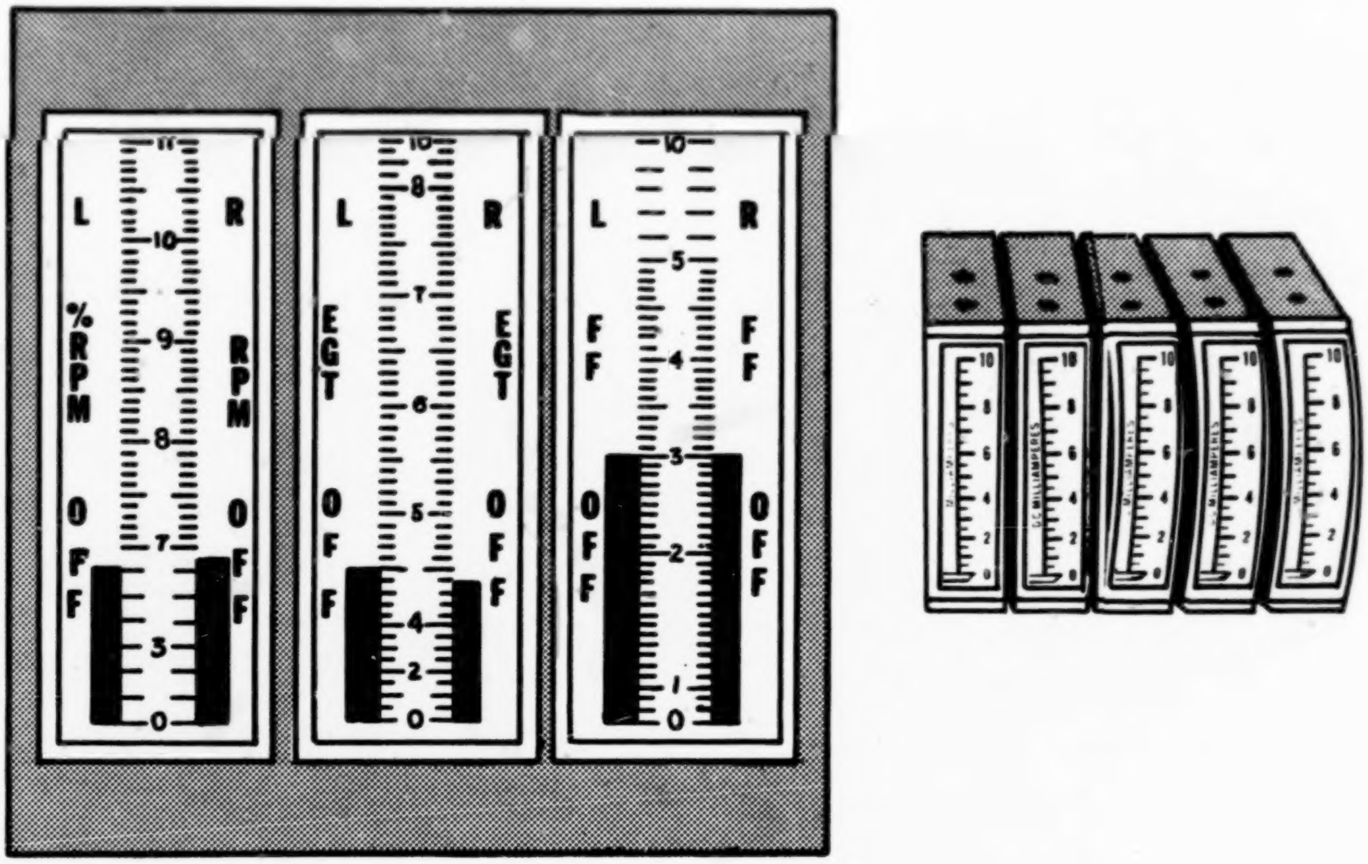

Fig. 3.5. Stacked Meter Movements.
(Gentape, 1964; Simpson, 1964)

Devices of the type discussed are available from many sources and in many forms from simple panel lights to fairly elaborate symbol displays and meter movements. A newer meter display that is particularly useful in displaying relative information is illustrated in Figure 3.5. The movements in such displays are either separately driven continuous tapes or separate meters assembled in close proximity to establish a pattern composed of separate readings. Displays of this nature are not generally stocked items of equipment but can be obtained from several instrument manufacturers (Triplett; Simpson; Gentape).

Film Projection Devices

The application of film projection devices for educational purposes has been used for a period of time that makes it unnecessary to elaborate the capability or potential of such devices. These devices can still produce the best quality and greatest range with regard to such parameters as size, brightness, contrast, resolution and color tone. Also, film is a medium of high information storage density, and although much of the information stored on pictures may be redundant, it is not likely that other practical techniques will soon surpass film on the basis of information stored per unit volume. This very characteristic of storage, however, causes film displays to be basically predetermined or stereotyped, and no new or previously unconceived display can be presented as a consequence of some response. Films can be selected as the result of a response, but the selection must generally be available in a file of possible alternatives.

Selection With Fast Access. Techniques for acquisition of information within a few moments exist in present day devices such as the U. S. Industries Autotutor and the Thompson Ramo Woolridge Mentor. These devices generally have a selection limited to frames that are judiciously located with respect to the frame being displayed or else the access time becomes significantly longer. Techniques have been developed with military and other display systems, however, that provide an access of a second or less to any one of several hundred frames.[1]

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[1] Observed on personal visit to Hughes Aircraft, Fullerton, California.

This capacity could be increased through the use of parallel units although the cost and complexity of such systems would increase in an exponential manner.

Real-Time Created Displays. Displays which are a function of the student's responses or actions and which utilize film can be simulated or approached by several techniques. One method is to superimpose symbols on a film projected background. This is often accomplished optically by having a program or input-controlled mirror position one or more high luminosity spots with respect to a background display. This is analogous to the lecturer who uses a light pointer for drawing attention to items on a chart or slide presentation. The schematic of such a technique is illustrated in Figure 3.6, where the position of the mirror can be both controlled and sensed by the program.

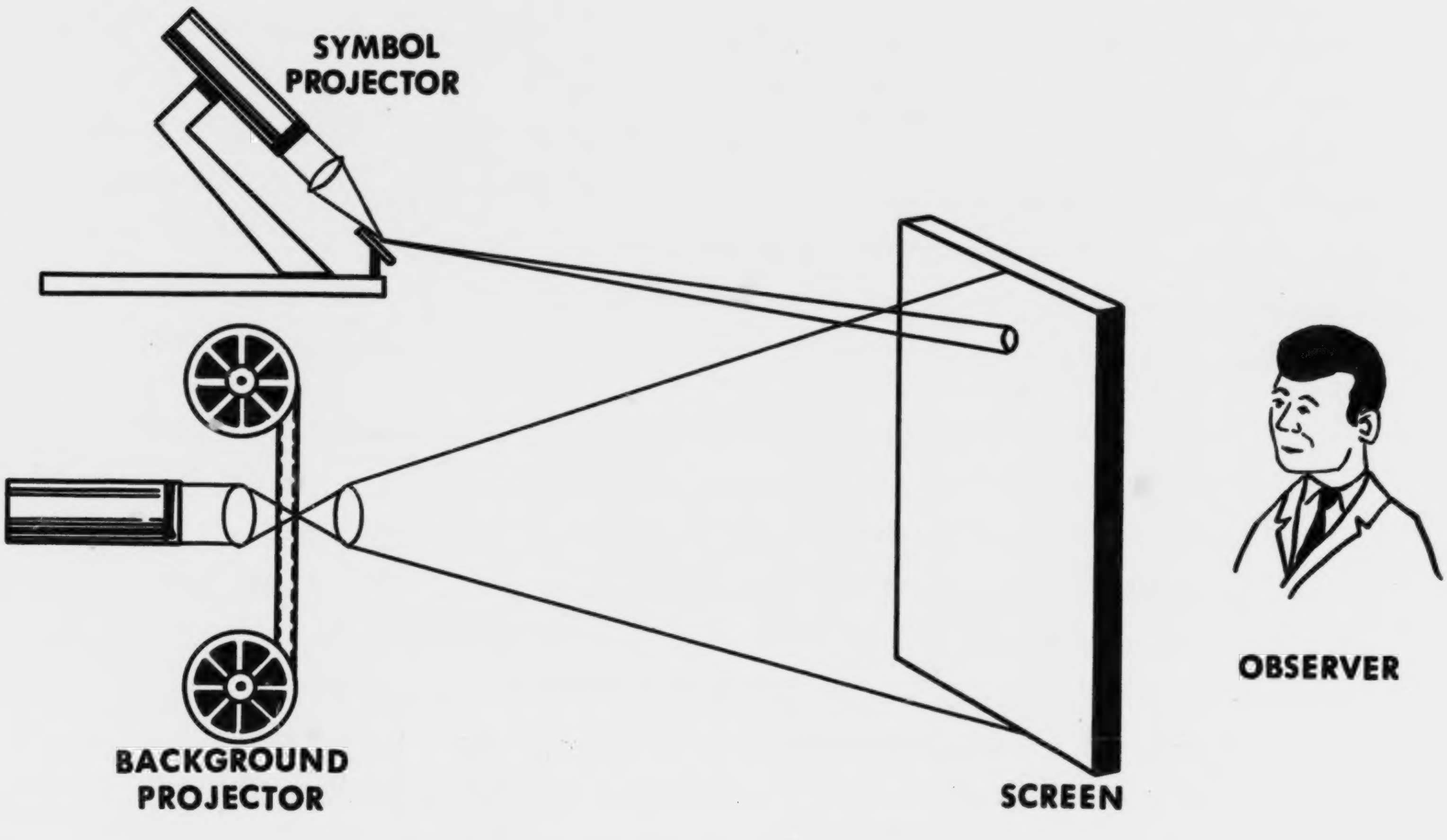


Fig. 3.6. Symbol Enriched Display.

Film displays have been described as being basically displays of prerecorded information; this is the manner in which most film displays are utilized. There are two developments, however, which bring the film display closer to real-time conditions. Real-time operation of any component is generally interpreted as meaning a reaction time that is short compared to the requirements of the system of which it is a part. One development is the use of developing techniques that can process film in 10 to 15 seconds. This provides the opportunity to photograph new information and update a display within this time period when the necessary film-handling equipment is available. To date, this technique has been used primarily to obtain overlay information such as pointers or special symbols by photographing the screen of a cathode-ray tube, developing the film, and projecting the image against an existing background.

The other development is with a film or slide utilizing a photochromic compound which consists of a molecular dispersion of reversible light-sensitive dyes. The individual molecules are switched from a transparent to an opaque state by light of the proper spectral distribution. Figure 3.7 illustrates the switching property of this material. Switching to the transparent state can be accomplished by either heat or illumination of the proper spectral distribution. Because of the thermal effect, there is a temperature-dependent decay of the opaque material to the transparent state. Decay time will vary, from a few seconds to an hour, depending upon the type of photochromic material. This property, if properly controlled, can be useful in indicating line direction by generating the line at a rate that allows the originating end to decay to a lighter shade than the terminal end. This provides line segments similar to aircraft vapor trails where direction can be indicated both by motion of an end point and/or the relative density or opaqueness of the indicating end. Photochromic material also possesses excellent resolution qualities (Haley, 1963) with an indicated resolution greater than 1,000 lines per millimeter (ordinary film is around 60 lines per millimeter), and although the molecules switch in a binary fashion, the material exhibits excellent gray-scale capabilities.

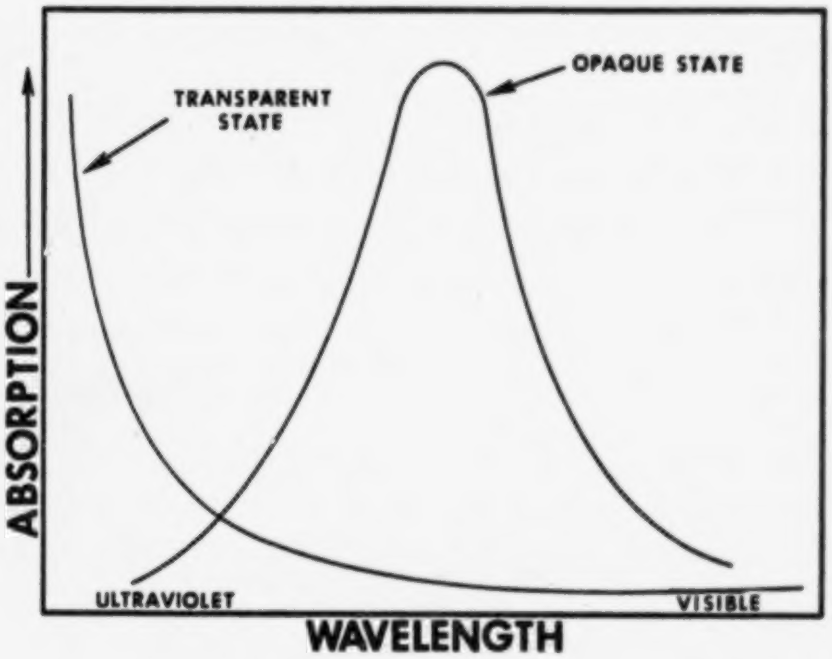


Fig. 3.7 Absorption Characteristics of Photochromic Dyes.
(Stambler, 1963, p. 94)

Large Screen Displays. A display method that is currently best handled by film techniques is large screen displays for group presentation. Rear projection displays as large at 10 feet by 10 feet have been developed for military applications where the use has included the rapid updating techniques described above. Several large systems have been described (Stambler, 1963) that are presently in a prototype development stage. These systems generally contain the system elements illustrated in Figure 3.8 although the particular components and techniques differ between individual systems.

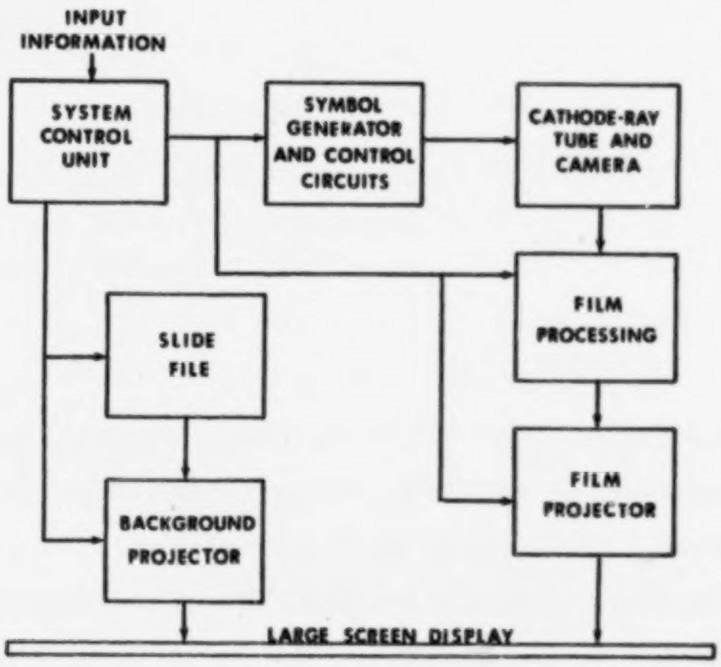

INPUT INFORMATION
SYSTEM CONTROL UNIT
SYMBOL GENERATOR AND CONTROL CIRCUITS
CATHODE-RAY TUBE AND CAMERA
FILM PROCESSING
SLIDE FILE
FILM PROJECTOR
BACKGROUND PROJECTOR
LARGE SCREEN DISPLAY

Fig. 3.8. Large Screen Display Elements.

Cathode-Ray Tube Displays

The display device most adaptable to various user requirements and changing display material is the cathode-ray tube. This device, using projection tube techniques, can present large screen displays, or, at the other extreme, can be miniaturized to hand-held individual displays. Light intensity can be made high enough to allow viewing in ordinary light conditions, and the display response times to new information is much faster than a human user can absorb the information. The cathode-ray tube also has the ability to provide user adjustment or brightness level which can be an important factor in changing environmental conditions.

There are many types of cathode-ray tubes with different characteristics depending upon the function to be performed. Those most likely to be encountered in the educational field include the standard single-gun television tube, color tubes, character generators, storage tubes, projection tubes, and perhaps some other special purpose types such as multigun tubes and flying spot scanners. The conventional television picture tube or kinescope is generally well understood, at least with regard to its capability, from its use in home television sets. In the home application in the U. S., these tubes operate with a resolution between 25 and 50 TV lines per inch, brightness between 70 and 100 foot-lamberts, large area contrast of around 30, and an aspect ratio (vertical to horizontal dimensions) of 3:4. Industrial or closed circuit television applications may have specifications differing from these because of particular requirements or for economic reasons, but in general the characteristics are similar to those of the home picture tube.

Color Tubes. Additional information is obtained from the pictorial display when color is added. There are numerous approaches to color-tube design although the shadow mask is the most common tube at present. This tube has a multidot tricolor phosphor screen in front of an aperture mask through which electron beams from three separate guns pass to excite the three separate spots on the screen (See Figure 3.9). Each gun is associated with a particular spot color (red, blue or green) and modulated in a manner that will result in the proper combination of the three colors on the screen. Because of the beam-interrupting action of the mask as the beams sweep out the picture, the light output as a function of single beam current is only approximately 20% of that obtainable with monochrome tubes without a mask. The brightness and contrast available with these tubes is only half that which is possible with present day monochrome tubes. The resolution which is primarily a function of spot diameter at the screen with both color and monochrome tubes is between 25 and 50 TV lines per inch.

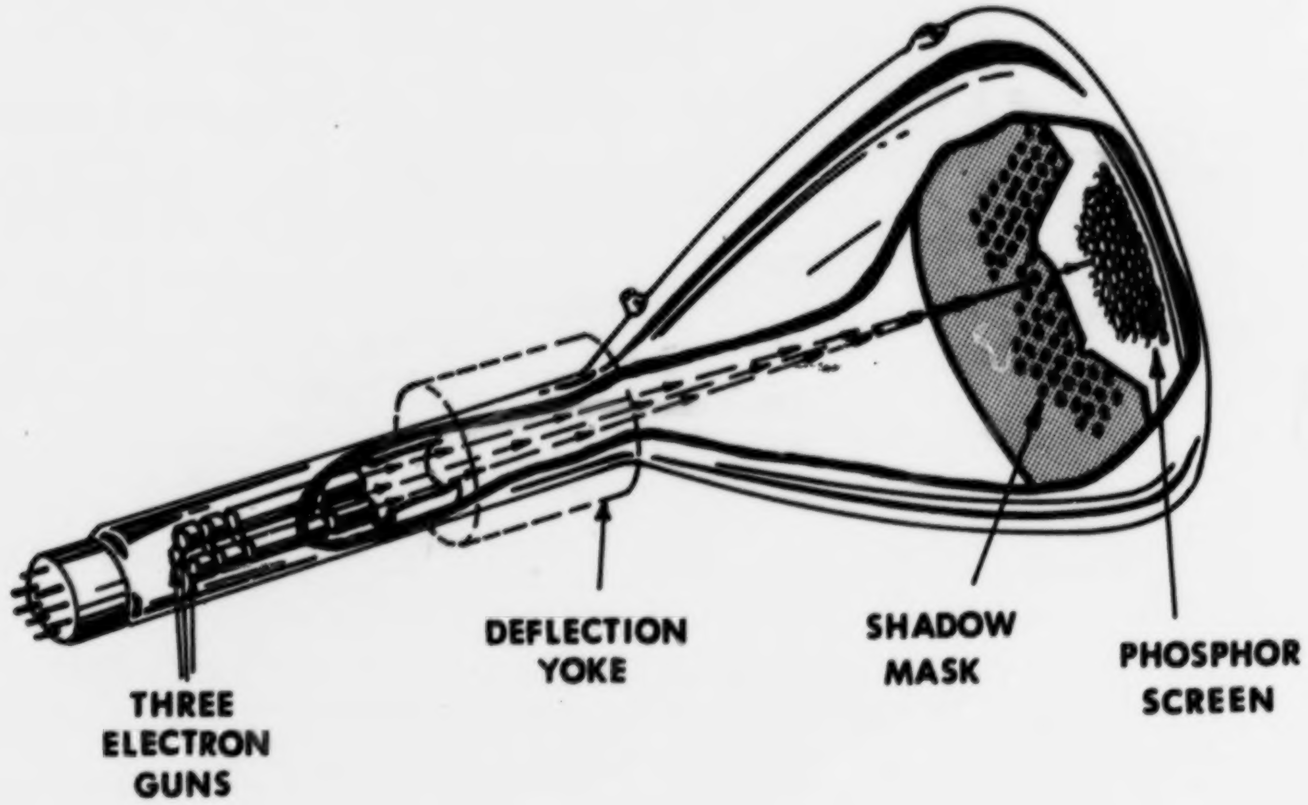


Fig. 3.9. Shadow Mask Color Tube.
(Zworykin & Morgan, 1954, p. 793)

Multigun Tubes. Where several traces must be generated at the same time, multigun tubes may be used. This may be necessary if it is not feasible to switch one beam back and forth between different signals in order to generate different traces or when the amount of flicker-free line desired on a tube exceeds that possible with only one gun. To prevent the sensation of flicker, each portion of a trace or display must be regenerated about thirty times a second, and if this is not possible with a single gun, several may be used to increase the amount of flicker-free display. Tubes with as many as ten guns have been made for special applications although the two-gun tube used in many industrial oscilloscopes is probably the most common multigun tube available (excluding consideration of color tubes).

Character Generation. Symbols or characters may be generated for cathode-ray tube (CRT) display by various means. One technique is to modulate the beam in such a manner that the desired symbol is traced on the screen at the desired location. This approach generally makes use of external electronic circuitry that provides the proper modulating signals for a specified set of characters. Another technique is to use special tubes containing a matrix of characters cut in a metal disc through which the electron beam is directed in order to display a particular character. The beam is directed to a given character of the matrix and after the beam is shaped by the matrix character it is deflected by additional signals to a specified position on the dis display screen. Another technique of character generation is to use the standard TV raster and to modulate the beam appropriately by such means as computer control of auxiliary scanning of symbol sets on film or other media to obtain the modulation. The technique best suited to a given application will depend on factors such as number and mixing of symbols. The special symbol-creating tubes are of course restricted to the character set contained within the tube. However, this technique is perhaps as economical as any, and the tubes are easily capable of generating 20,000 symbols per second.

Shallow-Depth Display Tubes. An innovation design of the direct view display tube is illustrated in Figure 3.10. This tube made by Kaiser Aircraft and Electronics has the advantage of a large tube face and very little depth. Also, by using transparent phosphores and deflecting plates, a display that a user can see through is possible. The beam of this tube enters one corner, and the vertical and horizontal deflection is accomplished by a series of conducting plates which bend the beam at the appropriate locations to focus it on a given sector of the display surface. This tube is still a rather special purpose device, but one which may find increasing applications in the future.

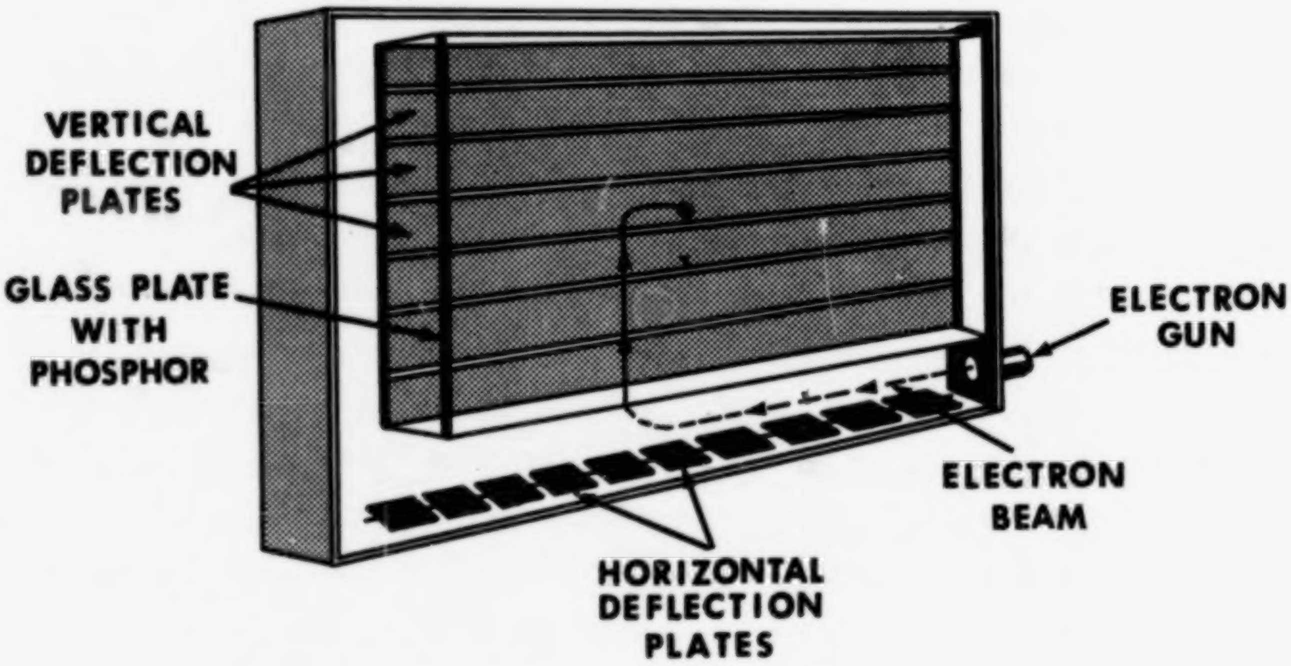

VERTICAL DEFLECTION PLATES
GLASS PLATE WITH PHOSPHOR
ELECTRON GUN
ELECTRON BEAM
HORIZONTAL DEFLECTION PLATES

Fig. 3.10. Shallow Depth Display Tube.
(Howard, 1963, p. 91)

Projection Tubes. In addition to the direct view display tubes which are not normally available in sizes larger than 27 inches in diameter are the projection tubes. These tubes are capable of high values of light output and can provide around 7 foot-lamberts on a 20 by 15 foot screen with the use of a good projection system. This light level compares with standards set by the Society of Motion Picture Engineers for first class pictures. In order to provide this level of illumination, the highlight brightness at the face of the tube is of the order of 30,000 foot-lamberts. The brightness is obtained by using very high accelerating voltages (80 kilovolts in some tubes) which create operational problems of x-ray and power-supply shielding. Also, these tubes must be cooled during operation and have relatively short life compared to the direct view tubes. However, where large screen displays with high information rates (rapid and unpredictable changes of display) are needed, the projection tube is one of the best developed techniques.

Storage Properties. Displays incorporating storage properties are desirable because many display situations do not require continuously changing scenes and in fact demand static displays for some period of time. The necessity of continuously supplying signal information for a non-changing display can present a serious demand to signal sources such as computers, and therefore, it is desirable to have a display capable of holding or storing information until a change is implemented. Cathode-ray tubes that perform this function have been built in sizes up to 21 inches in diameter although the large tube sizes are expensive and difficult to build. The principle of operation is illustrated in Figure 3.11. The storage assembly usually consists of a dielectric material which has a uniform negative charge when the tube is in the blank condition. A writing beam on bombarding this dielectric causes secondary electrons to be emitted, resulting in some degree of positive charge at those points which the beam bombards. To display the written traces, a flood gun in conjunction with collimating lenses continuously sprays a shower of electrons toward the viewing screen. The number of electrons that pass through the storage assembly and illuminate the screen is a function of the charge at any point, and hence, presents a copy of the image on the dielectric storage assembly. The negative areas repel the electrons back to a collection electrode; while the more positive the area, the more electrons it passes to illuminate the screen.

Storage tubes, in addition to holding an image or display for presentation, have the added advantage that the continuous stream of electrons to all points of the screen result in more light output than is possible when the display is generated by scanning. A scanning beam in a standard television receiver activates each point only thirty times a second and there is appreciable light decay between scans. With the storage tube light, outputs between 10,000 and 15,000 foot-lamberts can be obtained. The resolution, on the other hand, is not generally as good as with non-storage type tubes due to the defocusing action of the storage assembly. Also, many of these tubes have an erase time of the order of a half second which results in a noticeable blank time or interrupt interval between displays.

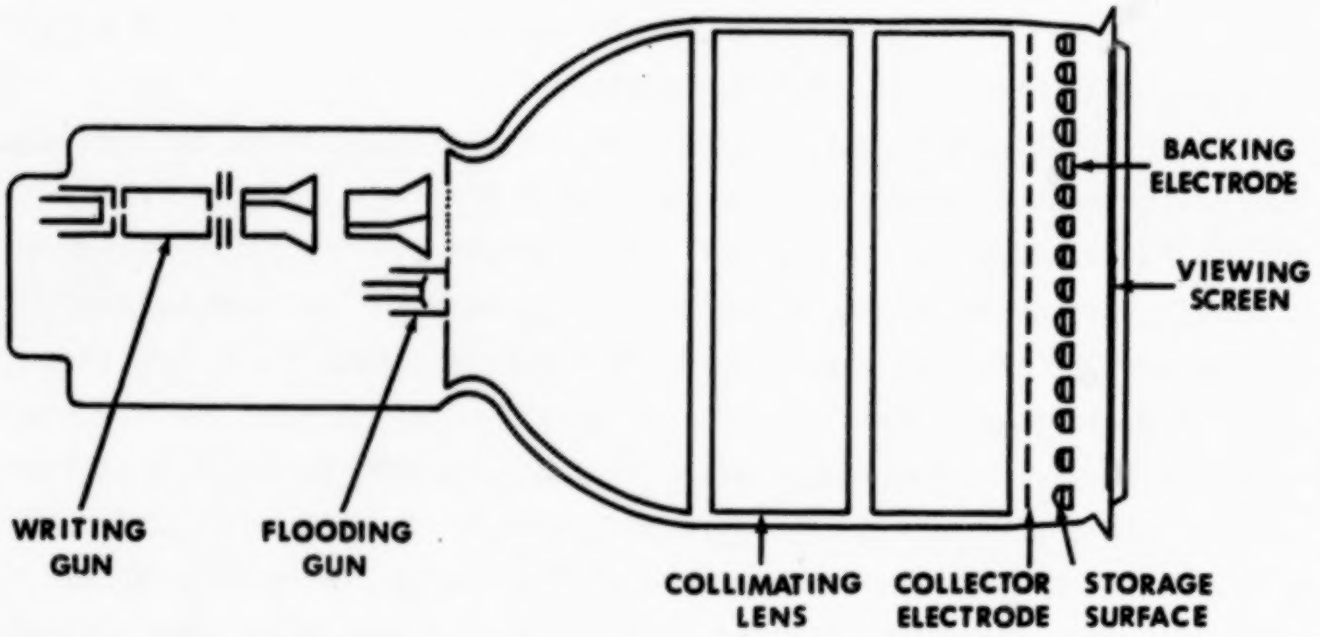

BACKING ELECTRODE
VIEWING SCREEN
WRITING GUN
FLOODING GUN
COLLIMATING LENS
COLLECTOR ELECTRODE
STORAGE SURFACE

Fig. 3.11. Cathode-Ray Storage Tube.
(Howard, 1963, p. 99)

Color-Storage Tubes. Still in the development stage, but holding promise for the future are color-storage tubes. These tubes contain all the elements that non-storage color tubes contain plus the storage-containing elements. A complex of beam-deflecting elements tends to reduce significantly the light output of these tubes. In some of the newer developments, however, some of the functions such as storage and color focusing have been combined in one element with a resulting overall increase in tube quality.

Static and Dynamic Display. A tube incorporating both static and dynamic display makes use of different beam energies on a dual-effects target to accomplish the simultaneous displays. This target dielectric is charged by the secondary emission phenomena described earlier, but can also be selectively erased by a high energy bombardment which overwhelms the secondary emission effect. At an intermediate beam energy, the writing and erasing effects cancel to result in the display of non-stored or dynamic information.

Storage-Camera Tubes. Although not a display tube, another storage device that directly relates to display devices is the storage-camera tube. This device has the characteristic of holding an image on its light-sensitive screen which can be continuously scanned by the reading beam. The reading beam is modulated by the stored image and then used to generate a signal that can be displayed at as many viewing stations as desired. The camera must obviously operate as a still picture shutter camera, but it has an additional feature in that multiple exposures can be made to give the effect of "strobbing" or an overlay of stopped-action pictures. Erasure with this type device is done optically and again takes in the order of one-half second.

Scan-Conversion Tube. One other type of storage device which again is not a display device in itself but directly related there to is the scan-conversion tube. These devices which are often called electrical-read, electrical-write storage tubes can be presented an electrical signal corresponding to a given display for one complete raster scan and then have a corresponding signal continuously read out to one or more display units. These devices operate on a principle similar to that of the direct-view storage tubes in that a dielectric screen is charged by a writing beam, but instead of having a flood gun shower electrons past the screen, a reading beam scans the surface and is modulated by the variations in charge which it encounters. This modulated signal is then amplified and becomes the input signal for standard display units. The resolution and storage capability of this type tube is quite good with up to 2000 lines per diameter being possible with continuously read storage times of many hours.

Three-Dimensional Displays. In any discussion of visual display techniques, consideration is usually given to the possibility of generating three-dimensional displays. Several approaches have been made in this direction, utilizing stereoscopic techniques or actual three-dimensional displays. Stereoscopic techniques generally require special glasses to observe the display and are therefore somewhat objectional. The actual three-dimensional displays include multiple layer or stacked devices to obtain a third dimension. Hughes Aircraft has built a "whirling dervish" (Howard, 1963) device which is a CRT with a phospher screen mounted on an internal disk that is spun at 1800 rpm. The disk, synchronized with the writing beam, can generate a three-dimensional display, but it is obviously difficult to build and operate. Other manufacturers have proposed similar approaches, but the state of the art is still developmental, and it is not obvious that the benefits of such display warrant the effort required to produce it.

Response-Detection Device. The cathode-ray tube may be used as an input or response-detection device as well as an output display or stimulus device when associated with a light pen. Figure 3.12 illustrates the technique. A light-sensitive device, usually in the form of a pen, is held near the screen of the CRT and when the light-generating electron beam passes the pen, a detectable electrical pulse is emitted by the pen which then can be correlated with the beam position. This relationship establishes the position of the pen which can be interpreted in accordance with the dictates of a particular program. This technique provides an intimacy between display and response that significantly reduces the possibility of translation errors that occur when switches or keys are used as inputs and must be correlated to the display. Also, the rate at which the beam refreshes each point of a display allows programs to be written that, in effect, can follow the motion of the pen under normal hand movement across the screen. Techniques of this sort have been described in papers (Stotz, 1963; Sutherland, 1963) related to the computer-aided design project at MIT.

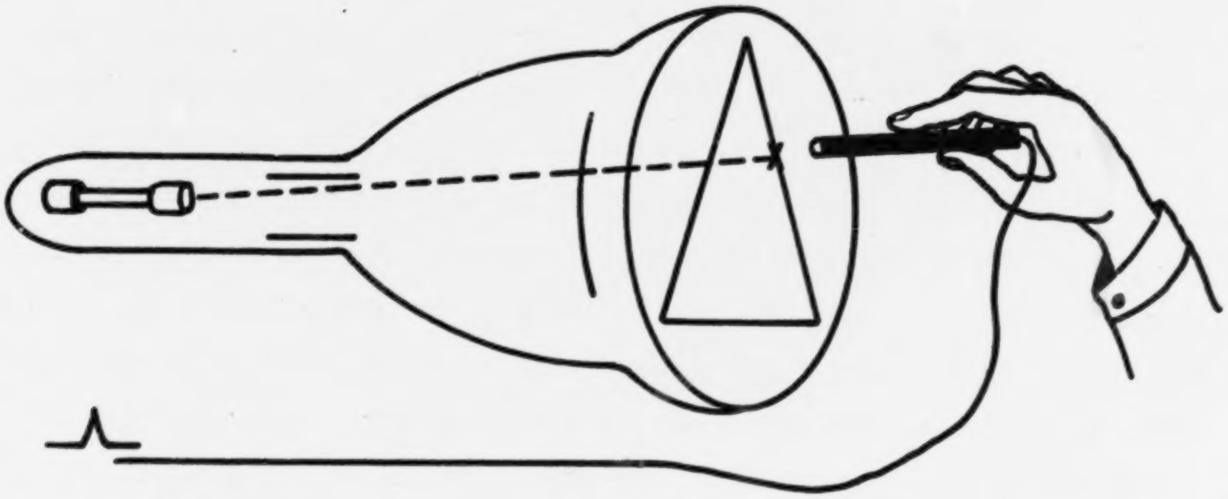


Fig. 3.12 Light-Pen Response Technique.

The discussion of a light-pen application to displays implies a program logic and sophistication that can be implemented only through computer devices. This report has not concerned itself with the techniques behind the interface, but it is probably appropriate to mention here that CRT displays making use of light-pen techniques and under control of a computer allow the generation of displays in response to a student's action that may never have been created before. For example, a particular character sketched by a student may be different from any other ever drawn and the display is required to present such characters. Also, it may be possible by utilizing current knowledge relating to pattern recognition to analyze such displays from a subject matter viewpoint and provide a very personalized and innovational instruction sequence. If a student is asked to sketch a triangle, the properties of his response may be analyzed and appropriate correction presented if necessary.

Electroluminescent Displays

There are, in general, three methods of stimulating phosphors to obtain light output; these are photoluminescence, cathodeluminescence and electroluminescence. In photoluminescence, ultraviolet photons are used to stimulate the phospher, and in cathodeluminescence a high energy beam of electrons as used in cathode-ray tubes is used to cause light emission. Electroluminescence is the direct conversion of electrical energy into light within the phosphor. The phosphor is contained in the dielectric of a capacitor which has at least one translucent plate through which the light can be emitted. Figure 3.13 illustrates the basic components of this type of light source.

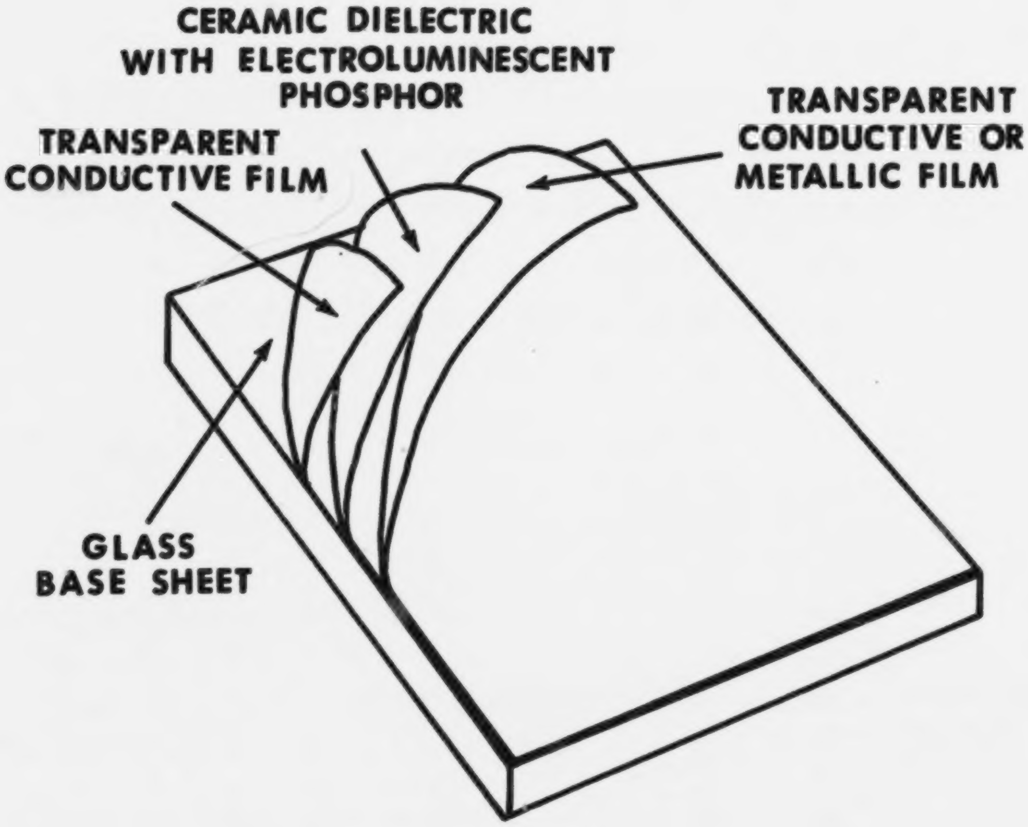
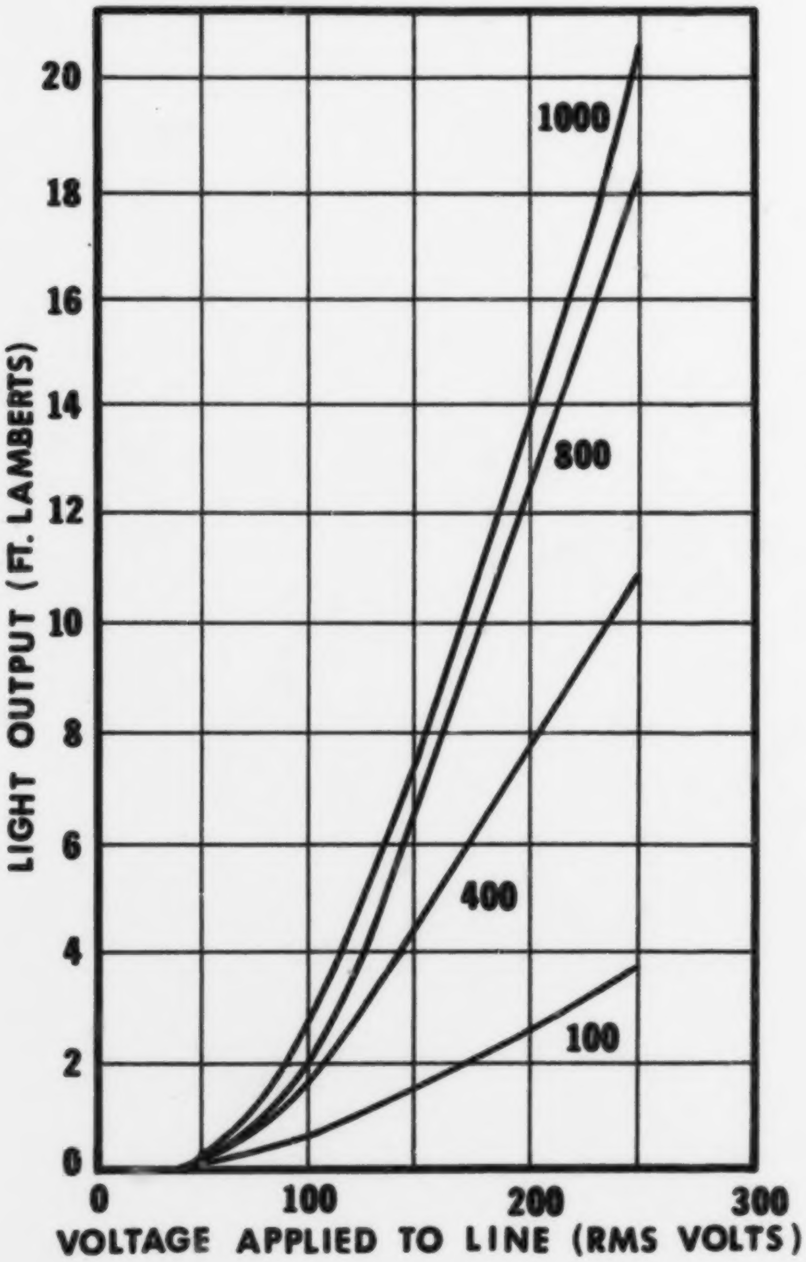

CERAMIC DIELECTRIC WITH ELECTROLUMINESCENT PHOSPHOR
TRANSPARENT CONDUCTIVE FILM
TRANSPARENT CONDUCTIVE OR METALLIC FILM
GLASS BASE SHEET

Fig. 3.13. Electroluminiscent Lamp.
(Sylvania Inc.)

The electroluminescent display is particularly advantageous where an area source of light is desired or where a flat or basically two-dimensional source is required. The individual elements (capacitors) can be constructed either on a rigid base such as glass or metal, or on a flexible material like plastic. When conditions require, the elements may be embedded in very durable materials that can withstand environmental conditions of mechanical shock and wear that would have catastrophic effects on evacuated bulb devices like the cathode-ray tube. These displays have a wide viewing angle without parallax ; light output is in the range of 10 to 20 foot-lamberts; and the power requirements are in the milliwatt range. Light outputs in the 80 and 100 foot-lambert range can be obtained by increasing the voltage and frequency. Figure 3.14 illustrates typical curves for brightness as a function of frequency and voltage.

Fig. 3.14. Variation of Panelescent Lamp Brightness. (Sylvania, Inc.)



Electroluminescent phosphors are obtainable in four different colors. These are green, blue, yellow, and white with the relative brightness of the latter three being around 60%, 50%, and 40% respectively that of the green. Color is also dependent upon the frequency of the electrical excitation; the green phosphor can be caused to shift to a bright blue by increasing the frequency from 400 cycles to about 20 kilocycles. Red is also available as another color by using a fluorescent dye; however, the light output is lower than that of the other colors.

Display Retention. The problem of display retention or storage which must be provided for most display techniques other than film can be accomplished in electroluminescent devices by utilizing a photocell feedback arrangement. Figure 3.15 illustrates one technique used to accomplish this storage function for individual segments of a display. When a given segment is activated by closing the set switch, light from the electroluminescent element causes the internal resistence of the photocell to decrease so that the electrical path from the power source to the electroluminescent lamps will be maintained even after the set switch is opened. To extinguish the element the power source must be interrupted through a reset switch. These photoconductive elements can be prepared in a thin layer form which allows a high density of elements, and the storage can then be made as a part of the display unit.

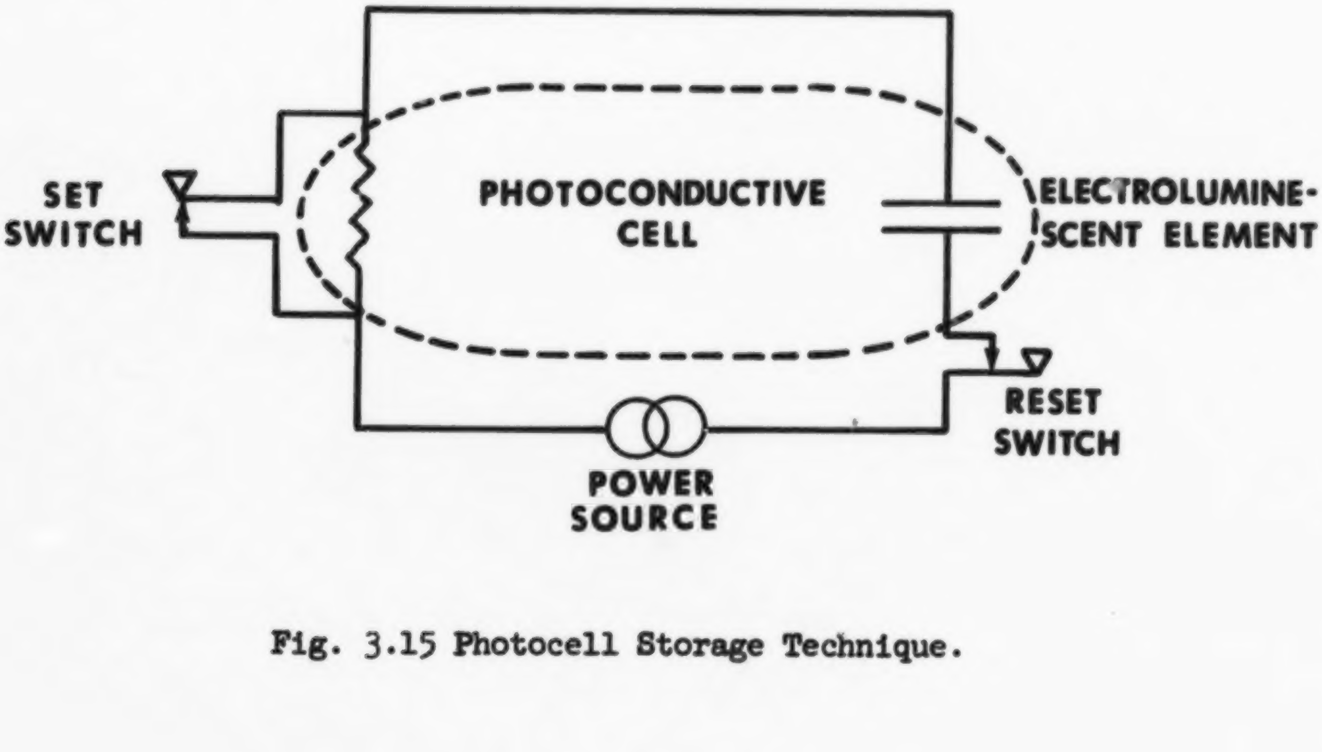


Fig. 3.15 Photocell Storage Technique.

Decoder. Another use of the photoconductive element is as a decoding device between the information source and the display. Figure 3.16 illustrates a technique of converting decimal information (one of ten) into a graphical display symbol. An examination of element D indicates that symbols may be formed by selectively activating different combinations of segments of the panel. The example of the number seven is obtained by activating the panel segments *a*, *f*, and *n*. The description of the photoconductive switch shows that if the electroluminescent segments *a*,*ff*, and *n* are each in a series with a photoconductive material, a means of turning the segments on and off would result. Element A of Figure 3.16 shows an electroluminescent lamp with the top conductive layer patterned into ten strips (0-9) resulting in a ten-element lamp. A non-strip photoconductive device is shown at element C. Each photoconductive strip is in series with its corresponding segment in the numeric panel. A mask or overlay is inserted between the electroluminescent and photoconductive layers. When electroluminescent strip number

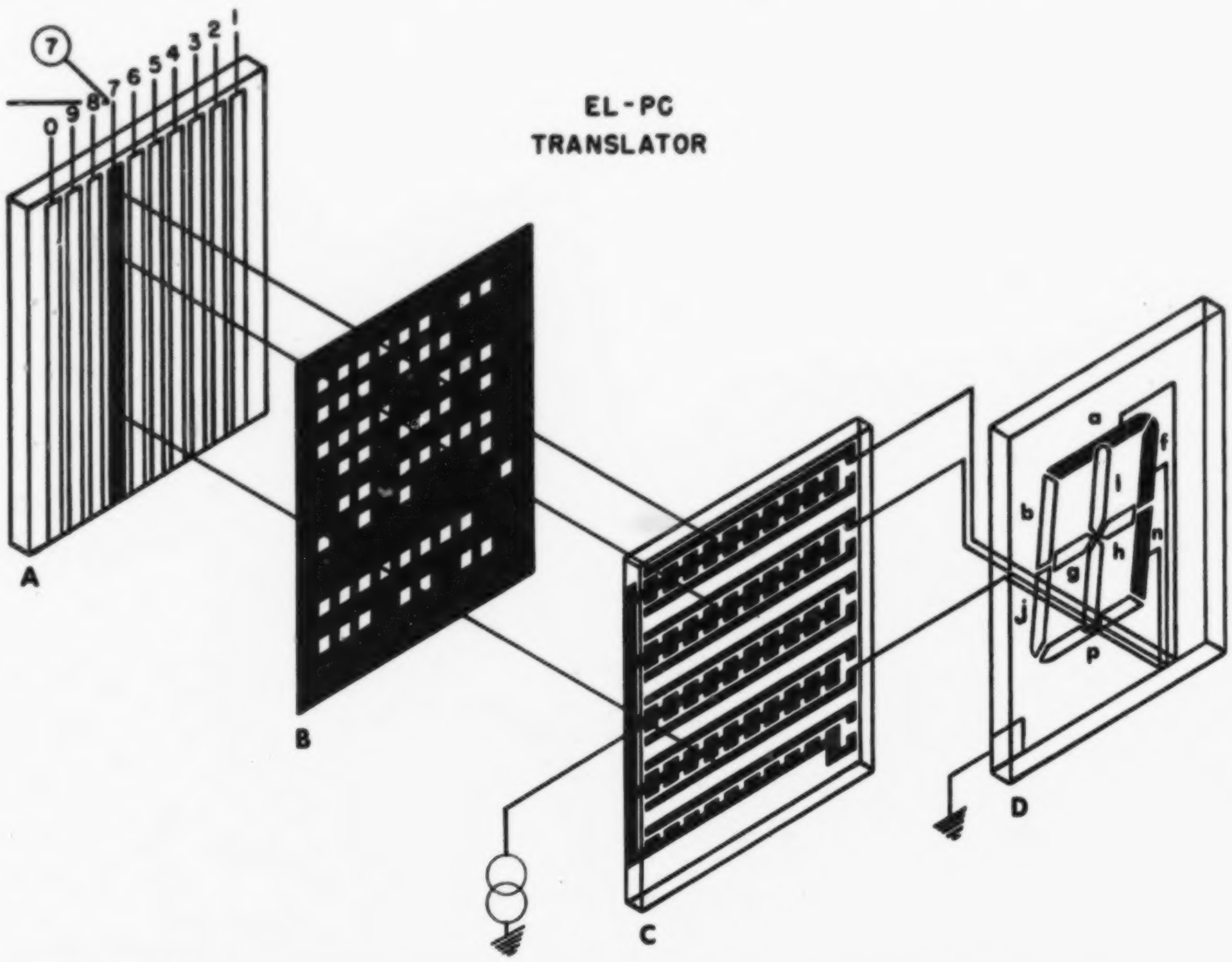


Fig. 3.16. Photoconductive Decoding Technique. (Sylvania Inc.)

seven is on, the light from it strikes only the a, f, and n strips of the photoconductive material. They will become conductive and the a, f and n segments of the display will light.

Arbitrary Pattern. Displays of rather arbitrary pattern can be created through the technique of crossed grid of conductive strips. Figure 3.17 illustrates a method of forming a coordinate system of separated "x" and "y" strips. Remembering that light is emitted only where there is capacitive couping, the application of a potential on one "x" line and one "y" line will result in a bright spot of light where the lines cross. This potential, however, causes one-half the voltage to be applied to the entire row and column which results in a faded "cross" effect. That is, each line will emit some light along its entire length although much dimmer than at the point of instruction. In some applications this "cross" effect may be useful, but if it is objectional, it can be suppressed by the incorporation of a non-linear restrictive layer. A single bright point is the result of the highly non-linear voltage-brightness characteristic of a non-linear resistor-electroluminescence combination. The conductive strips per ince is about 50 without suppression, and 16 with suppression. The response time, which is limited by the capacitance of the elements, is about ten microseconds.

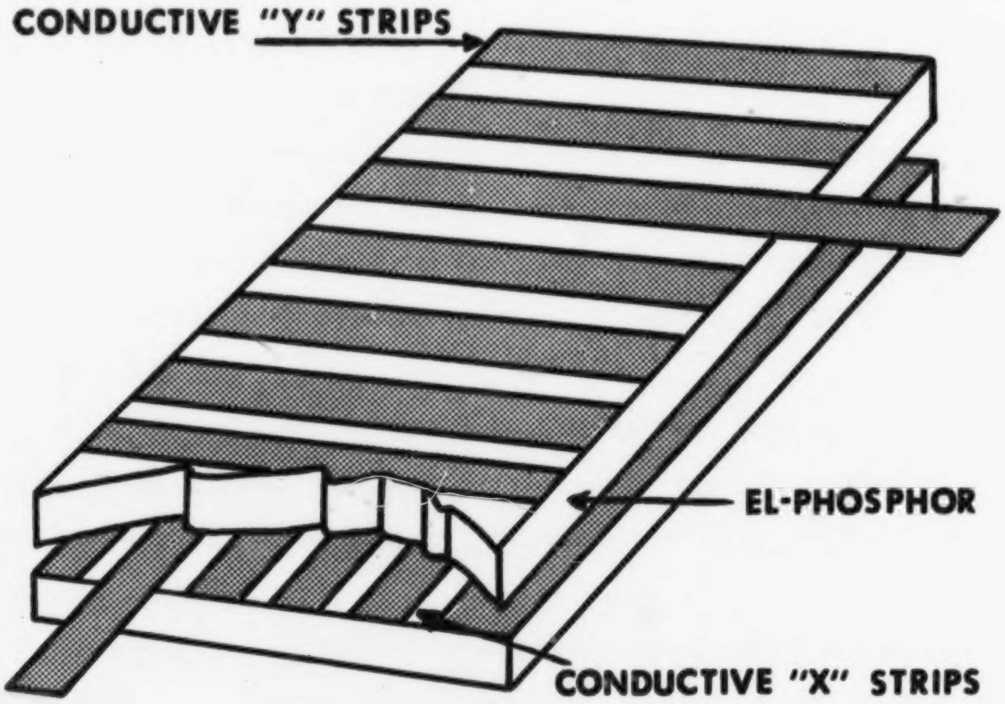


Fig. 3.17 Crossed Grid Display Technique.
(Sylvania, Inc.)

Developments in Electroluminescent Displays. Continuing development work with electroluminescent displays has included concepts of large screen (10 feet by 10 feet) displays, improved information storage methods, gray scales, resolution, and techniques of control. Developments with large screen techniques containing both gray-scale possibilities and self-contained storage in the display elements have been reported (Sack, Wolfe, & Asars, 1962) as well as new techniques of spot control utilizing piezoelectric materials rather than the technique of a crossed grid (Yando, 1962). The new spot control approach holds promise of simplified equipment and hence potentially more reliable displays. The continuation of work of this nature as well as continuing work on electroluminescent materials themselves will lead to interesting large area displays in the future.

Part B

Auditory Communication

Auditory stimulus presentation and response detection is a second major human-sensory mode and means of communication. If one is accustomed to learn by auditory presentation (as is true for young children), more rapid learning may result through its use than through other modalities (Underwood, 1949). Sounds are a significant part of the normal child's everyday experience and soon come to have certain meanings. These sounds need not be verbal languages but less complex sounds in the individual's environment. Simple sounds like car horns, fire whistles, door bells all have associated meaning for a particular person. More complex sounds such as the patterns generated during verbal communication are used to convey a variety of meanings depending upon their relationships within a sequence of sound patterns. The use of verbal sound patterns both for stimulus display and for a response mode is a "natural" method of communication in that it avoids the necessity of teaching the student to operate a special device (such as a pencil) in order to communicate.

Auditory stimuli when used in the educational area must be adjustable to both learner characteristics and subject matter requirements. In order to adapt to different display request rates and to avoid excessive "wait" times by the learner, some degrees of random access to the display of verbal material is required. When the recognition of spoken responses is involved, the equipment must be able to detect speech sounds at times initiated by the student. These requirements place restrictions on vocabulary size when access and recognition times in the order of a second are desired and tend to limit the amount of material that can be communicated in this manner.

Auditory displays are sequential and transient in nature, and an interrupted or missed segment can impair the following material. Means of requesting repeats are necessary to maintain continuity of information in such circumstances.

In general, auditory displays are advantageous, particularly with young children, because competency in speaking and learning are developed before precise visual discrimination required for reading, and, as mentioned below, because of the independence of the individual's orientation.

with respect to the display source. Also, when visual communications are heavily engaged or limited because of environmental conditions, the auditory channel is generally the next best method of information transfer.

General Considerations

Auditory methods of communication offer a number of advantages that are either unique or accentuated with respect to other modalities. The intensity range of sound levels accommodated by humans extends over ten decades of acoustic power although the range normally encountered in communication is under four decades.

The field of perception with respect to the hearer is virtually independent of his orientation with a uniform display (small gradient at the location of hearer) in the low frequency range (below 5000 cycles per second). This feature (e.g., that sound can reach the hearer regardless of his position in a room) is important in tasks requiring movement on the part of the hearer or in the performance of tasks physically disassociated with the signal source. Also, the ability to attract attention irrespective of orientation is possible because of this feature.

The binaural nature of the auditory channel provides directional properties and characteristics which allow the simulation of motion. This phenomena is easily controlled when headsets are used as the sound source. If the situation requires physical movement on the part of the participants, headsets might be undesirable and binaural effects would have to be obtained by proper room design and location of speakers.

Other parameters of auditory communication are loudness, duration, and pitch. These parameters are easily varied with present-day equipment and can be used to either adapt to a particular environment such as a noisy room or to provide additional meaning for a given display. Variations of this type can be made in discrete increments or they may encompass a continuum of variation as best suited to the application.

Stereotyped-Sound Displays

Communication by sound, as mentioned above, can embrace a range of complexities from simple tones to simple sound patterns to stereotyped messages to complex speech patterns. Table 3.1 lists common types of simple devices that are used to present "on-off" information or information about the existence of a particular condition. Horns, whistles, bells, and buzzers are used for displaying such information. Although these devices are primarily "on-off" devices, their information-carrying capacity can be extended by coding procedures such as varying the duration of signal, interruption rate, sequential pattern or similar techniques that add information. Chimes, for example, use sequential coding as the principal technique of encoding information. It is possible (Pollack, 1952; Pollack, 1953) to transfer between 6 and 7 bits of information per display for such elementary devices when properly encoded.

Table 3.1

Device	Frequency range	Attention getting ability	Noise penetrating ability	Possible stages
Horns	Low to High	Good	Good	On-off
Whistles	Low to High	Good if Intermittent	Good	On-off
Bells	Medium to High	Good	Good in low Frequency Noise	On-off
Buzzers	Low to Medium	Good	Fair	On-off
Chimes	Low to Medium	Fair	Fair	On-off
Oscillators	Low to High	Good if Intermittent	Good with Proper Frequency Choice	Range of Frequencies

Modified from: Morgan C. T., Chapanis, A., Cook, J. S., III, and Lund, M. W. Human Engineering Guide to Equipment Design. McGraw-Hill Book Company, Inc., 1963.

The oscillator is perhaps the most versatile of all the simple devices in that it is easy to vary such parameters as frequency, intensity, and sequential pattern in order to obtain a multidimensional display with one device. This unit, as the others in Table 3.1 are probably most useful as feedback and cueing displays rather than elements of subject matter displays.

Auditory displays with more information content than that described above encompass verbal messages of varying length. The technique most commonly employed in the reproduction of stored displays is the use of magnetic tape devices or of pressed discs (records) depending upon the application and quantity involved. Magnetic tape equipment used primarily as a voice recording and reproducing technique has the advantage of flexibility; it is easily altered with erase and rewrite techniques and is easily copied and edited. The advantages of disc recordings include less susceptibility to inadvertent damage and the loss of information. For large quantities of a given recording, discs are cheaper to produce than an equivalent amount of magnetic tape. Both types of storage have difficulty when fast access (order of one second) to randomly stored displays is desired. In fact, addressing techniques that will locate any portion of a recording do not appear to be standard equipment with devices making use of these recording techniques. Special equipment can be built for either locating a pick-up over a desired section of a disc or for moving a tape to a desired location; however, the addition of equipment of this nature substantially increases the cost of the basic equipment.

A recent technique used for recording relatively short messages (less than five minutes in length) is to make use of magnetic cards. Cards of a size and shape that will allow mechanical manipulation and selection are provided with magnetic coatings that can be scanned by reading and writing devices to either reproduce previously recorded messages or to record new messages on the card. One example of such a technique is used in the Edison Responsive Environment equipment manufactured by Responsive Environments Corporation of New York. This equipment has as one of its features a verbal display which can be associated with both a visual display and a student response through a keyboard device.

The technique employed is to use large cards which have one side available as a visual display and the other side coated with a magnetic material for recording the verbal displays. The recording format is arranged into fifteen groups of eight lines with ten seconds of reproduction available per line making a total of 1200 seconds or twenty minutes of recording available per card. The flexibility of programming and amount of audible display available with this technique is a big step toward fast random access of audible display. The Responsive Environment device does not, however, have card manipulation ability other than a sequential presentation of an ordered card deck.

Other types of magnetic card handling equipment have appeared in the digital computer field with National Cash Register's CRAM System and the RCA RACE System where random access to billions of computer characters is available with access times in the order of 200 to 400 milliseconds. This equipment is designed to store and retrieve information coded in pulse form at rates up to 100,000 pulses per second. The present design probably would not accommodate verbal recordings, but with some modifications and buffers that could act as speed changers to allow a high speed (100 KC) retrieval with low speed display (10-20 KC), this technique may well provide rapid access to a large volume auditory display.

Generated Sound Displays

Generated auditory displays for the purposes of this report will be interpreted as those compositions created from a set of simpler basic units than the composition itself. The arrangement and sequential timing of these units in relation to each other determine the composition; by varying the program or rules of composition, new displays never presented before can be created. Music can be considered to be in this category when it is created by supplying control signals to an instrument of some kind rather than selecting for display a previously recorded version. Music also has a particular advantage in that its units are well defined sounds that can be displayed in combination with other units according to the rules of a particular composition. Other types of audible displays, however, do not have such well defined units and in the case of verbal displays the characteristics of the units employed (phonemes, syllables, words) change depending upon context or location within a given composition. Rules of composition that will produce a pleasing (natural sounding) verbal display are not well established, and only approximations to verbal displays, although intelligible, can be made at the present time.

As a method of categorizing the various approaches to speech generation, F. S. Cooper (1963) differentiates between what he has termed compiled speech, synthetic speech, and speech produced from hybrid methods or combinations of techniques. Compiled speech is that produced from a random-access memory of pre-recorded words or phrases. The technique is to store recordings of words or phrases with careful attention to the most typical pronunciation and intonation for the type of presentation under consideration. The compilation consists of arranging these in the desired order of presentation. Synthetic speech is the controlled operation of a synthesizer using a phonemic description of the desired composition to determine the appropriate control signals. The technique is to apply a set of rules that specify formant frequencies and the transitions from one set of frequencies to another in order to create a particular sequence of phonemes. The application of an ordered sequence of such rules then forms a particular composition. The hybrid technique combines storage and synthesis. An example would be the storage of "standardized" sets of control signals that would be used to operate a speech synthesizer. For example, a set of control signals necessary to produce syllable-like sounds may be stored and the operation of the system would be to select the desired elements of the set in some particular sequence.

Compiled Speech

The approach most commonly encountered in practice where generated verbal displays are used are those of the compiled speech category. A number of devices based on this principle have been reported. A system built by the Teleregister Corporation (Van Gelder, 1964) to provide compiled announcements of stock market transactions to subscribers of the system has been reported. This system has a memory of only 62 words or parts of words and compiles announcements from this limited vocabulary by spelling the abbreviations of a stock listing. The limited vocabulary (comprised mostly of the letters and numerals) is adequate because of the specialized nature of the announcements and the context in which the messages are formed. The subscriber is expected to understnad the special terminology and format in which announcements are presented. Each word or unit of this system is 350 milliseconds or less in duration and longer words are broken into two separate parts that are joined during the compilation process.

IBM has recently announced an Audio Response Unit capable of providing a vocabulary of 128 five hundred millisecond words or part words. This system is capable of serving up to 48 different outputs and is presently limited to a message length of 38 words or part words. This system composes messages at high speed onto a temporary storage unit which then presents the composition at normal speech rates to the output associated with that storage unit. The audio response unit operates in conjunction with a digital computer which determines the message composition by specifying a sequence of words to be read into any particular output storage unit. The initiation and composition of any particular message is thus under program control and may be constructed to satisfy some particular operating condition. For example, in a course of college chemistry, a request may be made for the formula of alcohol. The computer upon receiving such a request will then compute and generate the necessary sequence of control signals to call forth from the audio unit the proper sequence of stored sounds that will create the desired formula.

The above techniques have made use of magnetic recordings which are stored on rotating cylinders in order to obtain fast access to any desired word. Other recording methods are available such as the Cognitronics Corporation's optical methods which utilize photo-electric detection of light modulated by passing through a photographic pattern of the sound desired. The basic function of all these units, however, is to provide sequential access without noticeable delay to any of the units of the vocabulary and to provide the ability to present these in any order desired.

The techniques of sound storage and retrieval (referred to above) become expensive relative to other techniques of storage and retrieval as the vocabularies become large (1000 words or more). A more economical way of storing such sounds would be on magnetic tapes which are capable of being addressed to the location of a particular sound unit. The composition of a sequence of sound units would then have to be collated on a temporary storage unit and played back to the listener after the entire message has been collated. This is necessary since the access to various portions of the main tape storage can be in the order of seconds or even minutes to get to a particular sound unit. This composing time, therefore, eliminates the possibility of fast replies (within a second) or audible presentations immediately following the initiation of some action.

The effect of a limited vocabulary is indicated by the required spelling rate for free text such as newspaper articles. Spelling rate is defined as the percentage of words that must be spelled when verbalizing free text because the desired word such as a proper name did not exist in the vocabulary available. It has been indicated (Cooper, 1963) that with a vocabulary of 7000 words, a spelling rate of about 5% would be expected with free text, and this should drop to about 1% with a vocabulary of 20,000 words. Vocabularies of this size seem well beyond the present capability of fast access systems. However, as is implied by applications in limited fields such as time announcements and airline departures, much smaller vocabularies can be gainfully employed with a low or non-existant spelling rate. Preliminary investigations have indicated that a vocabulary of around 500 words would be adequate for limited subject matter lessons in the elementary grades such as described in Chapter 2.

Synthetic Speech

In synthetic generation of auditory composition, the application of a set of rules activates the control signals associated with a synthesizer in order to produce meaningful sounds. Perhaps the type of synthesizer most generally known is the vocoder which has been experimented with since the mid-thirties. The vocoder, operating as a communication device, has both an analyzer and synthesizer of speech sounds. The analyzer converts the speech sounds into control signals (usually digitally encoded signals) which are transmitted to the synthesizer which then reconstructs the speech pattern. For purposes of generating speech sounds that have not been previously uttered, only the synthesizing portion of the vocoder and the rules or formulas for determining the proper sequence of control signals are needed to generate meaningful sounds. Figure 3.18 illustrates the basic items of equipment incorporated in the synthesizer of a common

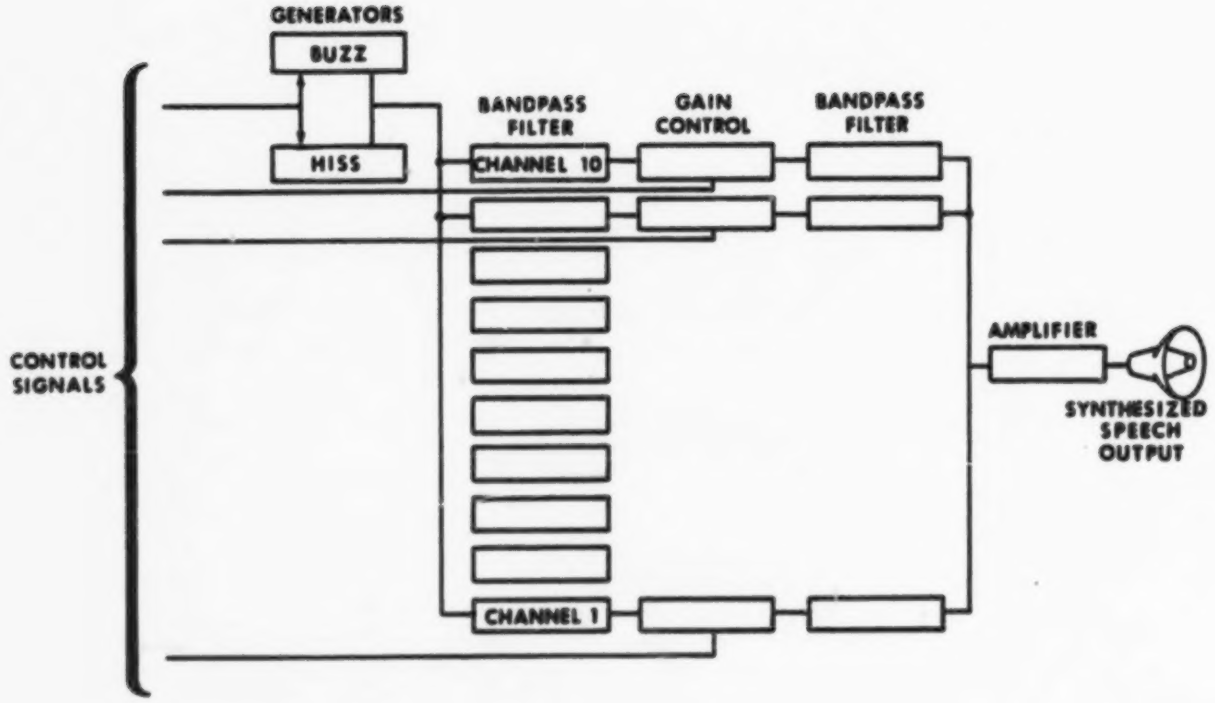


Fig 3.18. Fixed Channel Vocoder Synthesizer

type of vocoder. These items are the buzz and hiss generators and the associated bandpass channels. The buzz generator is used to create the fundamental frequency (usually in the order of several hundred cycles) and its harmonics. The hiss generator creates a broad spectrum of frequencies used in synthesizing the unvoiced consonants formed by the breath passing over the lips, teeth and tongue. The ten bandpass channels determine the amount of energy transmitted through that portion of the frequency spectrum which they control. One control signal determines whether the input is buzz or hiss and other signals determine the amount of energy transmitted through each of the ten separate channels. The output of these channels are then combined in a summing amplifier and presented as synthesized speech to an output speaker.

Other types of synthesizers include relatively simple devices such as a pattern playback which synthesize intelligible sounds by producing the harmonics specified in accordance with a pattern drawn on a spectrograph. The spectrograph illustrated in Figure 3.19 specifies the harmonics desired as a function of time for each and the transitions from one harmonic range to another. The spectrographic pattern is generally read photoelectrically

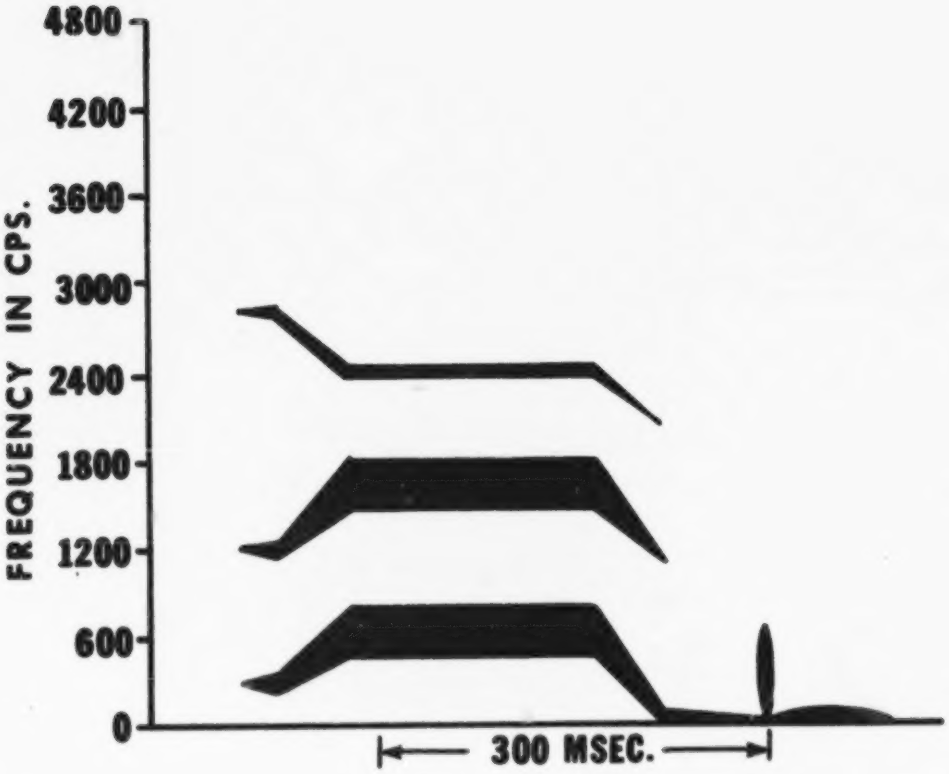


Fig. 3.19. Spectrographic Pattern.
(Cooper, 1963, p. 145)

by using either transmitted or reflected light from the spectrogram. A tone wheel is used to create the fundamental frequency and harmonics needed to synthesize intelligible speech. This device is basically quite simple in its operation but it is also monotonous in nature. The pattern playback devices are primarily used for research purposes and the study of the theory of speech.

Another type of synthesizer used experimentally is illustrated in the schematic diagram of Figure 3.20. This device called a resonant synthesizer adjusts the resonant (natural) frequencies of a set of circuits whose frequencies correspond to the primary resonances of the vocal tract. These circuits are driven by the outputs of buzz and hiss generators. By controlling parameters such as the resonant frequencies of the circuits, amplitude and frequency of buzz generator, and amplitude of hiss generator, intelligent speech sounds can be created. The synthesizer illustrated in Figure 3.20 (Estes, Kerby, Maxey, & Walker, 1964) contains a separate circuit for the fricative sounds in order to improve the naturalness of the speech.

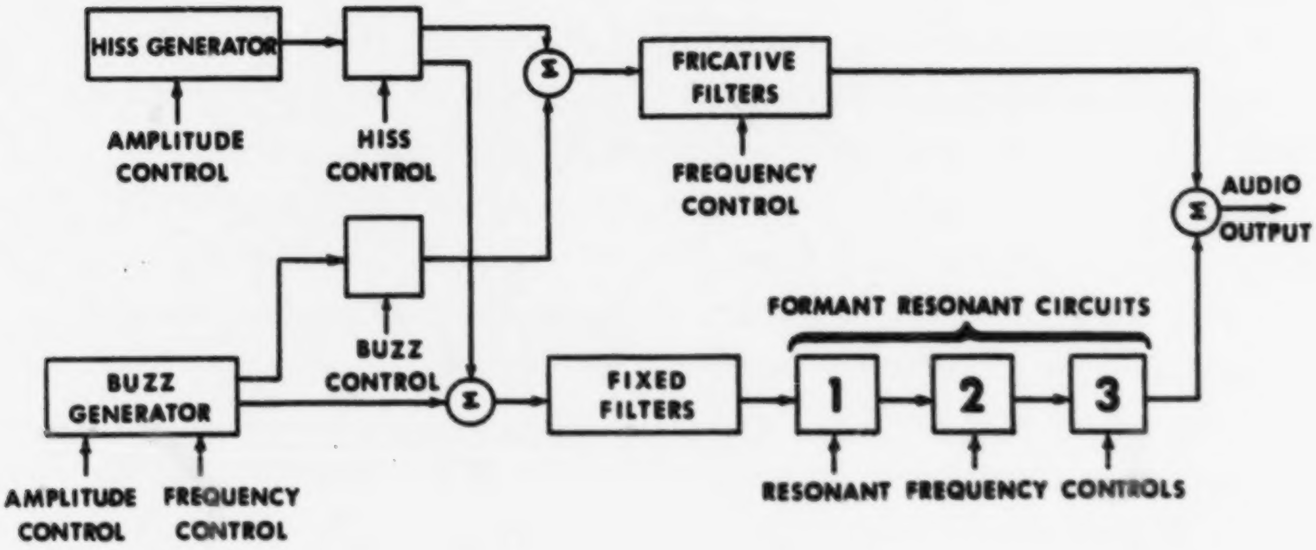

HISS GENERATOR
AMPLITUDE CONTROL
HISS CONTROL
Σ
FRICATIVE FILTERS
FREQUENCY CONTROL
Σ
AUDIO OUTPUT
FORMANT RESONANT CIRCUITS
BUZZ CONTROL
BUZZ GENERATOR
Σ
FIXED FILTERS
1
2
3
AMPLITUDE CONTROL
FREQUENCY CONTROL
RESONANT FREQUENCY CONTROLS

Fig. 3.20 Resonant Type Speech Synthesizer.
(Estes, et al, 1964)

The vocal tract analogue is another type synthesizer used for research in the synthetic generation of speech. This is an electrical simulation of the human vocal tract usually constructed by multisection transmission line techniques. The characteristics of the line are then varied to correspond to changes in the vocal tract during articulation. Research utilizing this approach (Stevens, Kasowski, Fant, 1953) has been conducted at Massachusetts Institute of Technology.

Digital computers have also been used to synthesize speech patterns on magnetic tapes which can then be used on regular tape recording equipment. This work (Kelly & Gerstman, 1962) implies the possibility of talking computers when the transducer of the tape recorder is a part of the computer system.

Synthetic generation of speech as produced by the techniques described above implies the existence of a description of the speech pattern desired. Much of the work to date in this respect has been to study units of speech or the acoustic cues that listeners use in perceiving speech and from these to specify the characteristics of the sound pattern needed to produce meaningful speech. A set of rules of this type have been summarized (Liberman, Ingemann, Lister, Delattre, & Cooper, 1959) which are minimal in the sense that the rules have been kept as simple as possible, consistent with intelligible speech. These rules make use of the phonemic descriptions of speech which specify the requirements of the individual phonemes. The interactions between successive sets of rules must also be considered when specifying a succession of phonemes as neighboring units affect the rules for a given phoneme. Also, to achieve a degree of naturalness to the display, rules specifying pitch and intensity information can be added to these basic phonemic rules. There is much work left to be done in this area, and the actual creation of libraries of spectrograms or control sequences for a particular synthesizer today usually involves some refining after the application of a set of rules by a "Listen and Change" procedure.

Hybrid Techniques

Hybrid techniques of speech generation combine both storage and synthesizing techniques in the generation of speech sounds. The stored units may be recorded sounds such as phonemic or syllabic transcriptions that are combined according to specified rules in the output device, or on the other hand, the storage may consist of tables of control signals required to operate a particular synthesizer. The display desired would be described by some code (perhaps written text) which is then converted into the required machine code and sequence necessary to operate the particular system. In the case of stored sound units, the machine code and sequence would be principally the addresses in storage of the sound units and the order and timing associated with each.

A hybrid system making use of stored syllables has been described (H. F. Olson, 1964) that will accept coded input, and with a storage capacity of approximately 1000 syllables will generate intelligible speech for most practical applications. A syllable as defined for this system is not necessarily the same as that used in a conventional dictionary, but is more specifically a grouping of two or more phonemes considered as a unit. A diagram of the basic elements of this type are shown in Figure 3.21. The decoder and word selector translates the coded specifications of the required speech into a set of machine instructions. These instructions together with the associated time controls and synchronizers cause the proper sequence of syllables to be read out of the main storage unit and assembled on a temporary storage unit from which it is then transmitted to an output unit.

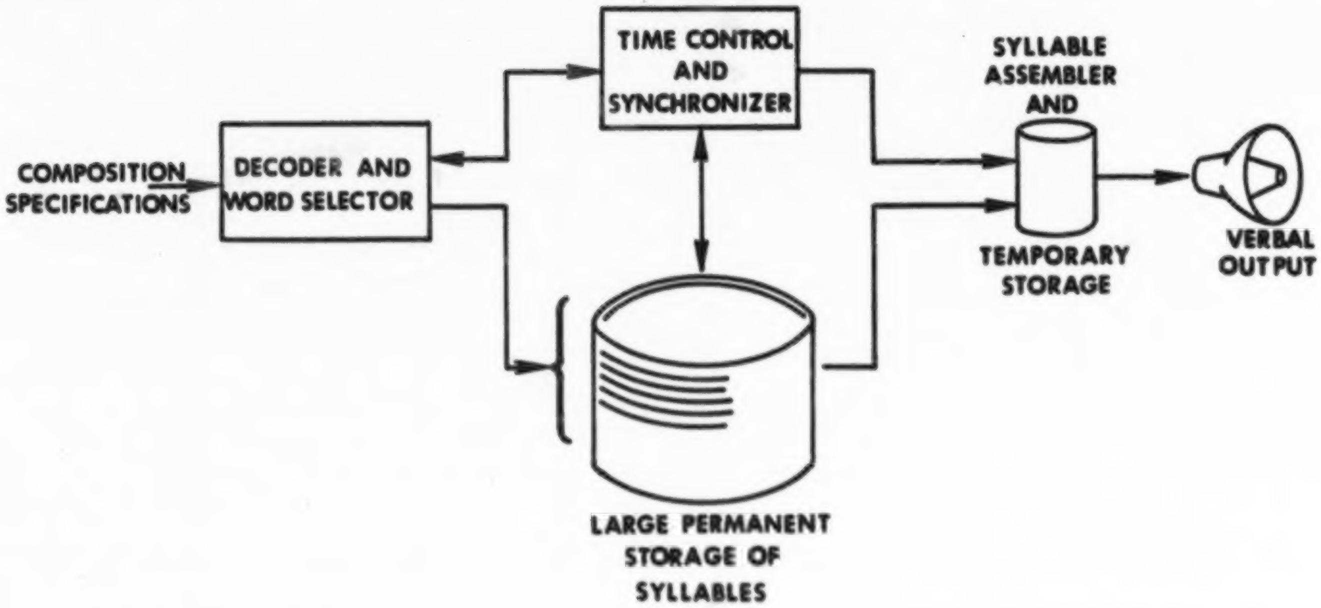

COMPOSITION SPECIFICATIONS
DECODER AND WORD SELECTOR
TIME CONTROL AND SYNCHRONIZER
SYLLABLE ASSEMBLER AND
TEMPORARY STORAGE
VERBAL OUTPUT
LARGE PERMANENT STORAGE OF SYLLABLES

Fig. 3.21. Speech Synthesizer Utilizing Syllable Storage.

An example of a system incorporating the storage of synthesizer control signals is the resonant synthesizer illustrated in Figure 3.20. In this system nine control signals are used to operate the synthesizer. The amplitude and sequence of these signals for specified segments of speech are stored on some associated medium such as magnetic tape or punched cards. The sequence of speech segments desired, and operations on them such as repeating segments or changing pitch of a group of segments is required as input that will generate intelligent speech.

Comparison between Display Methods

In comparing the different approaches toward the generation of speech the most obvious distinction is perhaps the trade-off between storage requirements and design sophistication. The generation of speech by compiling words requires a very large storage but fairly simple logic while speech generated by rules requires only modest storage but more sophisticated logic. It has been estimated (Cooper, 1963) that the storage required by the different techniques to accommodate a vocabulary of 20,000 words as being of the order of 400 million bits for compiled speech, about 40 thousand bits for synthetic speech, and between one and ten million bits for the different hybrid methods. It has been pointed out (Peterson & Sivertsen, 1960) that the number of units becomes very large whenever the choice of unit differs from one of the "natural" linguistic units such as word, syllables, or phonemes, and even among

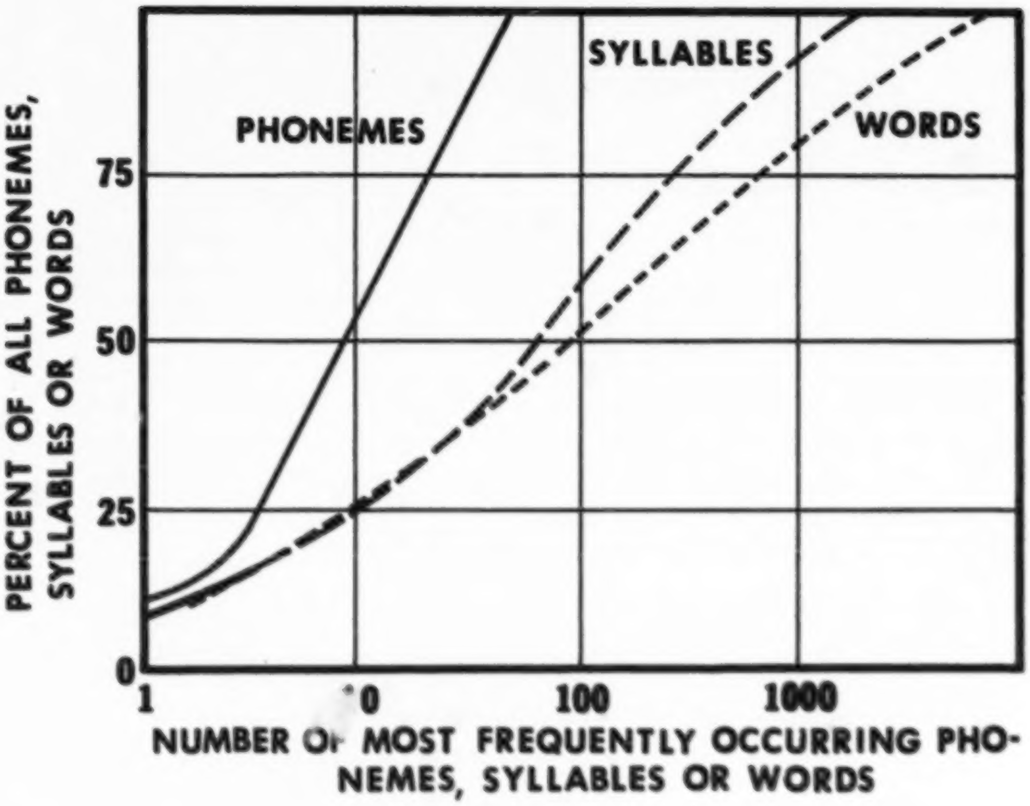


Fig. 3.22. Speech Unit Storage Requirements. (Olson, 1964, p. 94)

such units the storage requirements differ significantly as indicated by the chart of Figure 3.22.

The communication bandwidth requirements or bit rate is another factor to be considered in the design of speech generation equipment. If the input bit stream generated the speech, 30,000 to 50,000 bits per second would be required to generate intelligent speech. The vocoder on the other hand produces good quality speech with an input rate of around 2500 bits per second, and the resonant synthesizers operate with around 1200 bits per second which is within normal telephone line capabilities. At the low end of the spectrum Olson (1964) has pointed out that a compiling system utilizing syllable storage requires only about 23 bits per second to produce speech at normal rates of talking. This figure is interesting in that it corresponds closely to the rate at which humans have been found to be able to assimilate and process information (Quastler, 1956).

Output quality should also be considered in evaluating different approaches to speech-generating systems. Unfortunately, this is a subjective measurement, and to date, evaluations are generally given in terms of relative intelligibility of "naturalness" of sound. Comparisons between the different techniques of generation are not known to exist and, in part, would probably not be meaningful at the present state of development. A user of equipment of this type will probably want to make intelligibility tests of words or sentences in order to be able to predict the results of the use of such a system. Techniques for making such tests are covered by Morgan, Cook, Chapanis & Lund (1963) in their discussion of speech communication.

The application for which speech generating equipment is desired will determine the relative importance of the different features in the various approaches. In the instructional environment much work remains to be done to establish the requirements of a particular subject matter area and to determine what compromises should be accommodated to realize an effective and economical approach.

Speech Recognition

Verbal communication is normally a two-way process with each communicant participating in both speech generation and speech reception. The implementation of speech generation has been discussed above, and within certain limitations involving vocabulary size, response time, and degree of intelligibility, has been shown to be possible with equipment available today. The recognition of speech by equipment, on the other hand, is a more difficult task and only a very limited approach toward its realization has been achieved to date.

The recognition of speech is difficult not only because the acoustic cues of verbal communication are not yet completely understood, but also because the receptor must be capable of adjusting to the allowable variations within the presented speech. This problem was not encountered with speech generation as the uniqueness or artificiality of a particular presentation was assumed to be accommodated by the listener, and the major concern was that an acceptable level of intelligibility be attained. As a receptor of speech, however, the interface and its associated equipment must be capable of adapting to different characteristics, such as speaker intonation, variation of loudness, and rapidity of speech that will be encountered in a particular environment. Also, a reasonable degree of background noise must be accommodated in most operating environments, adding to the difficulty of accurate recognition.

In a student-subject matter interface environment of the equipment must react without annoying delays to the responses of the student. This property places a speed requirement on the equipment and constrains the amount of analysis that can be done on the received speech patterns. This property is probably most important with the younger students where the immediacy of information feedback is specially significant to the learning process.

The techniques used in the analysis of speech patterns include an amplitude-frequency-time description of the received speech. This description is basically obtained as with the analyzer portion of a vocoder where bandpass filters segment the input into frequency channels which have separate amplitude analyzing circuits. These channels are then sampled as a function of time to obtain a pattern that can be analyzed. In addition to this rather basic information, other information bearing components such as the shape of the envelope, frequency deviations, and dissymetry are often added to increase the degree of discrimination. The processing performed on the extracted parameters is generally a function of the particular approach being studied or used. It may vary from a very specialized approach operating with speech cues as vowels and consonants or it may be of a more general pattern recognition scheme which attempts to detect the salient and consistent parameters of a repeating pattern no matter what the origin of the pattern.

Several implementations of speech processing systems have recently been described (Sakai & Doshita, 1963; Olson, 1964). Sakai and Doshita have described a system in which the phoneme is used as the basic recognition unit. This system requires some adjustments for individual voices and with Japanese monosyllables (which contain a consonant and a vowel) scored around 90 percent correct for vowel parts and 70 percent for consonant parts. This system, in principle, may accept all the connected speech sounds although the present implementation requires that the words be clearly and somewhat slowly spoken.

Olson (1964) has described a speech analyzer which translates the input into a syllable code by means of the basic information obtained from an amplitude-frequency-time description. The system described has a recognition vocabulary of around fifty words and an accuracy of 98 percent when an average of 200 voicings or repetitions of a word were used to establish the code that represented the word. This system also demonstrated some ability to extrapolate between individuals. The accuracy of 98 percent was maintained over about half the available vocabulary when an individual of national origin different from that of the individuals used to establish the code provided the input to the analyzer. The accuracy for the remainder of the vocabulary varied from near 98 percent to almost zero.

Another system described by Arnold Lesti and based upon a mathematical procedure of emphasizing features of the signal that are to be recognized and de-emphasizing those features which are to be ignored has been in operation for several years. This system has a capability in its present hardware configuration that is roughly equivalent to the system described above (Olson, 1964). The system, which is in the more general pattern recognition category, can be encoded in various manners. It can be established in a manner that emphasizes the characteristics of an individual voice and hence recognizes words only when spoken by the same individual. This is accomplished by using the same individual to establish the code for the words of the desired vocabulary. At the other extreme, by using voicings of many individuals the code is generalized so that the word is recognized over a range of voicings such as men and women or individuals of different dialect. Figure 3.23 illustrates a flow diagram of a procedure involving both the establishment and the recognition of audio or speech patterns. Figure 3.24 illustrates actual equipment used with the systems described by Olson and Lesti.

The present state-of-the-art of speech recognition appears to be the ability to discriminate between sound (syllables, words, etc.) vocabularies of perhaps several hundred words (with hardware extensions of the above systems) with some generalization between speakers. As generalization or tolerance for a range of individual speaker characteristics is increased, the accuracy of recognition of large vocabularies decreases. That is, there is a trade-off between generalization and discrimination. Phrases and short sentences can be recognized when words are distinctly

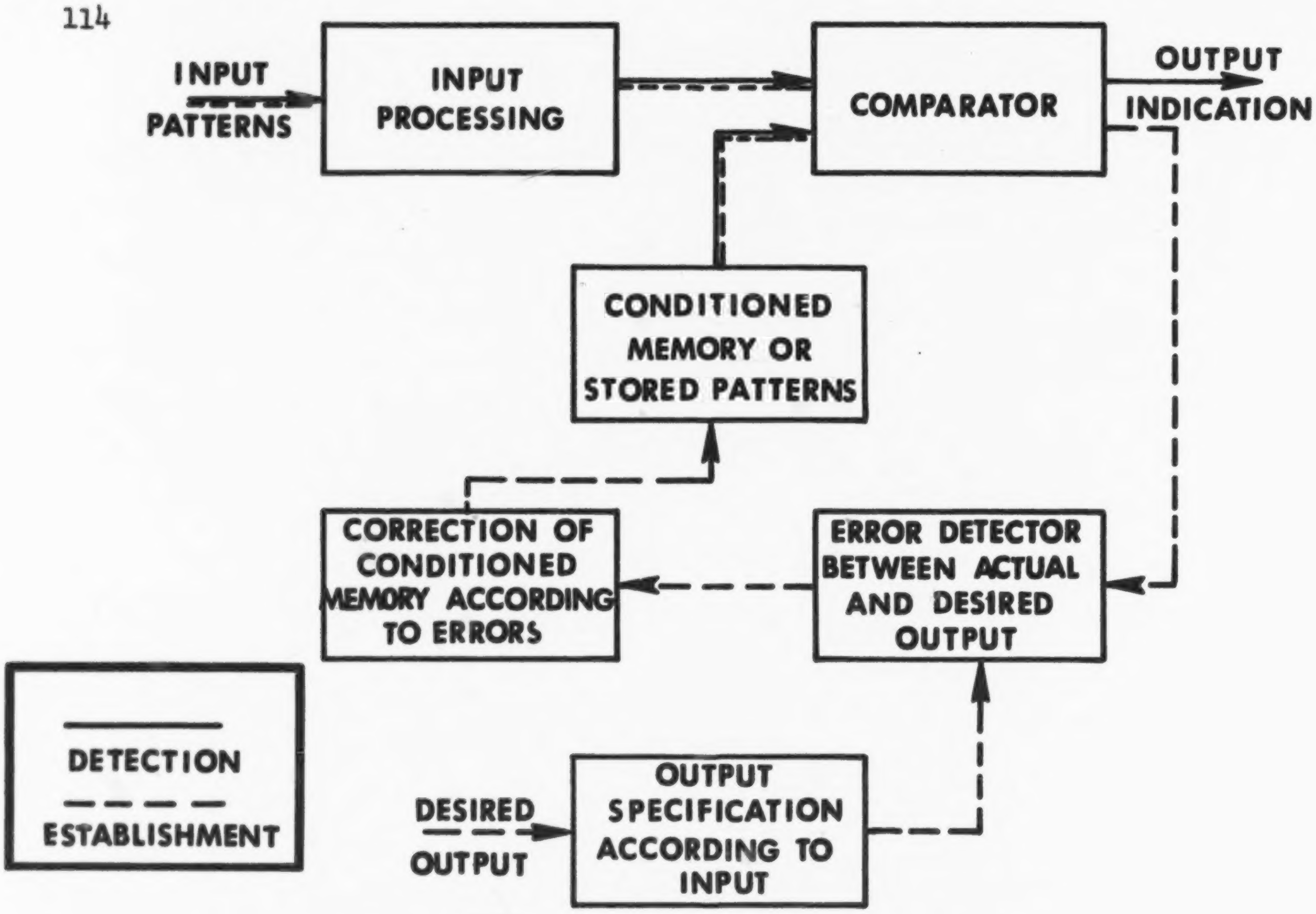
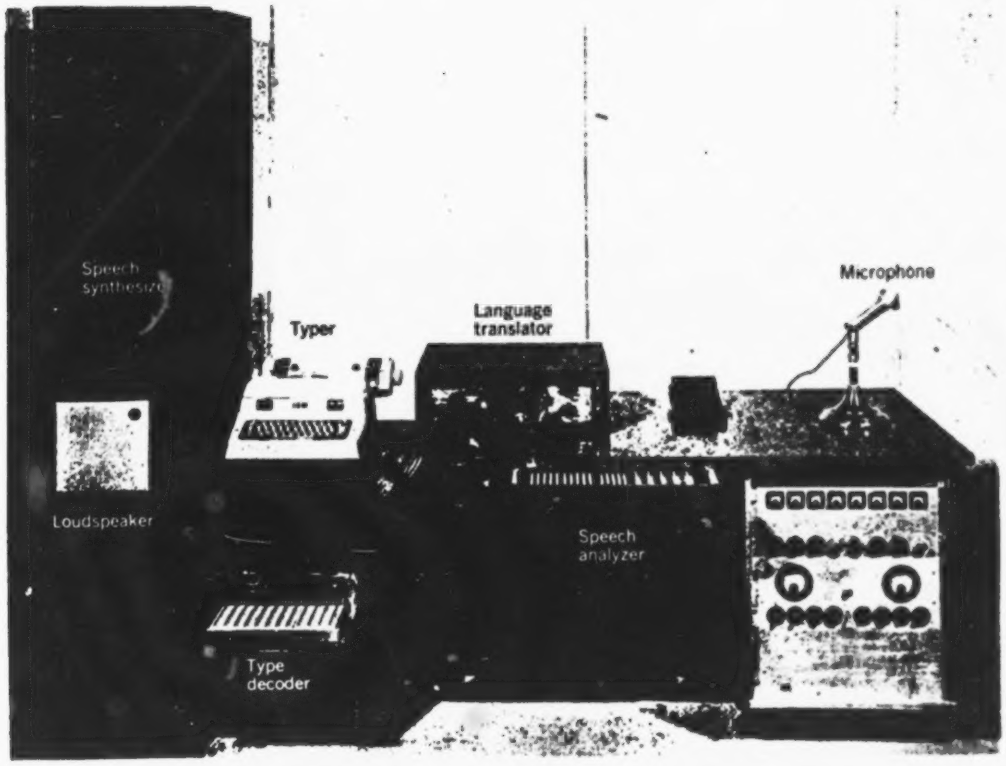

INPUT PATTERNS
INPUT PROCESSING
COMPARATOR
OUTPUT INDICATION
CONDITIONED MEMORY OR STORED PATTERNS
CORRECTION OF CONDITIONED MEMORY ACCORDING TO ERRORS
ERROR DETECTOR BETWEEN ACTUAL AND DESIRED OUTPUT
DETECTION
ESTABLISHMENT
DESIRED OUTPUT
OUTPUT SPECIFICATION ACCORDING TO INPUT

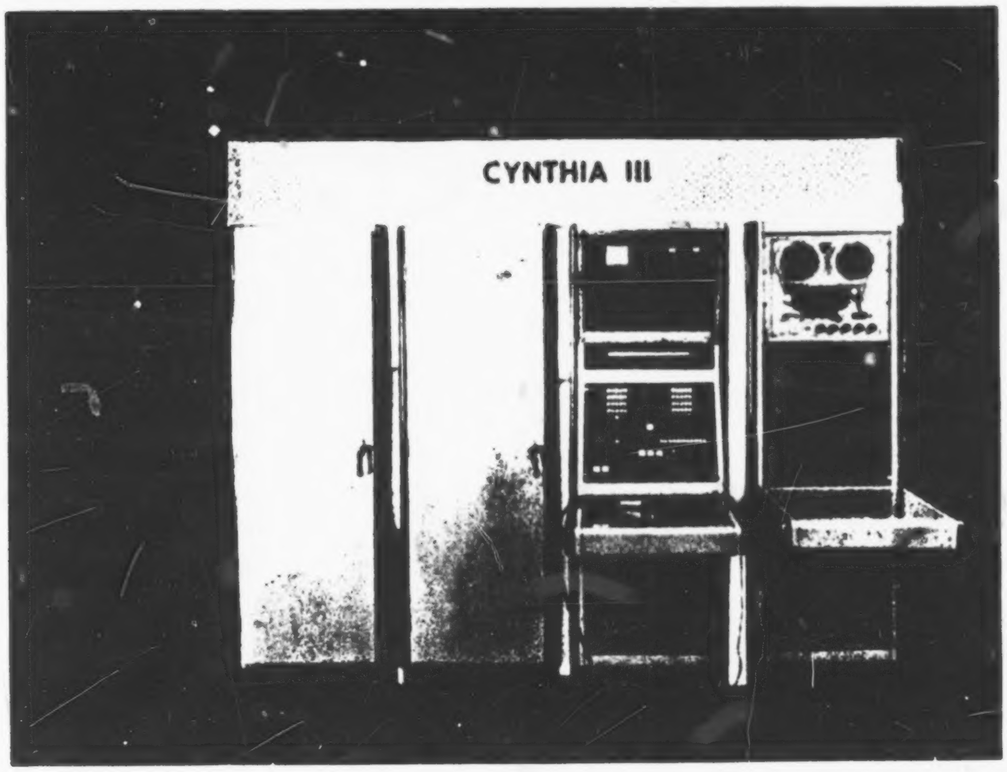
Fig. 3.23. Pattern Establishment and Recognition.

spoken and care is taken not to slur adjacent words. In other words, systems capable of recognizing a specified sequence of words are possible, but the probability of correct detection decreases with the sequence length since any missed portion invalidates the entire sequence. Speech recognition in the presence of noise has not been investigated to any significant extent, although in an experiment with the system of Lesti only slight deterioration was experienced with monosyllable words in a background of white noise where the energy ratio of the signal to noise was 3 decibels in the bandwidth employed.

Systems having the above capabilities are still in the research phase of development and are generally quite expensive. However, for applications where limited vocabularies and short phrases are feasible and where the amount of generalization between dialects and speaking habits is not too great, present techniques can provide an operating system.


Speech synthesize
Typer
Language translator
Microphone
Loudspeaker
Speech analyzer
Type decoder

RCA System
(From H. F. Olson, "Speech Processing Systems,"
IEEE Spectrum Vol. I, Feb. 1964)


CYNTHIA III

Andromeda Corporation System
(From A. Lesti, News Release of
Andromeda Corporation, March, 1963)

Figure 3.24

Developmental Equipment Used
For Speech Recognition

Part C

Response Devices

In an instructional system, as in an engineering process control system, communication between the human participant and the information-providing environment in a two-way channel. The human must be able to respond to states of the environment, dictate requests for appropriate action, and observe the actions or states of the environment. The channel from human to environment is often a limiting factor because of the encoding burden imposed upon the human. In order to input information of more than minimum content, the human is required to use specialized devices whose operation must be learned and whose technique is generally different from that used in communicating with other humans. Hence, the human becomes burdened with operational details which do not contribute directly to the accomplishment of the objectives of the system. Increasingly sophisticated equipment and the development of problem solving technique (e.g., pattern recognition) can remove some of the encoding burden placed upon the human and generally facilitate the communication between the human and the environment.

Requirements of response devices and techniques for the instructional process demand a wide range in both the nature of responses accepted and the degree of variability of particular responses. As indicated in Chapter 2 these demands arise from the characteristics of different subject matters and from the learning conditions required to bring about the increasingly precise responses which comprise subject matter mastery. For example, in the early stages of learning, wide response tolerances are acceptable and simple "yes-no" responses may suffice. As learning progresses, more precise responses to complex stimuli are desired which often require constructed responses with graphic and verbal properties. In keeping with the scope of this report, response devices included in this section consider only the interface aspects, that is, the nature of the equipment in direct contact with the human user. Where sophisticated equipment such as computers are required in order to use the device, their existence and capability have in general been assumed.

The discussion of response devices in this report is limited to devices capable of detecting overt responses and will not consider techniques of detecting such things as eye movement or brain waves. The interpretation of such involuntary responses to the learning situation is not clear at this time although such responses and other physiological phenomena may be an important area for investigation. Also, since young children and school system environments are involved, instruments attached to the learner have not been considered. Discussion is also limited to new devices and innovational use of existing techniques; the coverage of such present devices as keyboards, switches, knobs, and levers would be of little value since their use and application is already well understood.

General and Human Engineering Considerations

In order to increase effectiveness, response detection devices should be designed to place a minimum of constraint upon the user with respect to such control characteristics as position, expenditure of force, excessive interpretation or coding of response, or any actions competitive with common response habits. Also, response devices should be recognized as display devices since they guide the nature of the response and often are used to indicate the nature of the response performed. Hence, display requirements must generally be considered in the design of response detectors. The use of these devices should be functionally obvious, and when one device is used for different applications, its function for each application must be clearly apparent.

When several or many response devices are incorporated within an instructional environment, they should be arranged in a manner that provides not only clear visibility but also facilitates access without increasing the probability of inadvertent operation. Where many devices are involved, these considerations can pose a serious problem; however, when only a few devices are relevant at any given time, the unused devices can be made inoperative. In general, those devices which are active in most situations should be located near the center of the responding environment. It is generally desirable that active devices should also incorporate operational feedback such as an audible click or visual indication that confirms detection of the response. Devices in the inoperative condition require a feedback signal that differs from that used with the same device in the operative condition to prevent misdirected effort.

For those devices having linear and near linear motions (such as levers) that are associated with linear displays, the control-display ratio (C/D ratio) becomes a significant parameter. This ratio is defined as the linear distance of control displacement to the distance of the resulting display movement; the control movement is measured at the position where the user's hand grasps the control. For small rotary controls that affect linear displays, the C/D ratio is defined as the ratio of control rotations to distance of display movement. The optimum C/D ratio is that which minimizes the total time required to make the desired control movements within a specified error range. A number of different factors effect this ratio including the display size, tolerance requirements, physical configuration of the device itself, and viewing distance. In general, empirical measurements are required to optimize the ratio for a particular design, and it has been shown that a good ratio can save from one to five seconds in positioning time (Jenkins & Connor, 1949; Jenkins & Karr, 1954).

To minimize error, the direction of movement of a control must be related appropriately to the change it induces in the associated display. In general, this relationship should satisfy existing design practice, standardization, and response norms. Response norms refer to control-movement habit patterns that are consistent from person to person without special training or instruction. For example, an inward or upward motion is almost always related to an "on" or activated state of a mechanism.

It will often be the case that several methods or techniques are possible as response detectors for a particular environment. This is particularly true with an educational interface since it is frequently possible to structure subject matter in a manner that will be consistent with the devices selected. Chapter II of this report has generally considered interface devices from the viewpoint of those most desirable for learning a given subject matter. In an actual operating environment, however, other factors such as cost, versatility, safety, reliability, and availability must be considered in relation to its value as a pedagogical device.

Experimental Devices

Techniques for communicating responses or instructions of a greater complexity than a simple "yes-no" or "start-stop" usually require a "letter writing" approach such as the typing of instructions on a typewriter keyboard or the manipulation of dials and switches in some specified manner. This can be a difficult undertaking even for mature users when the format requirements and operation of such devices must fit within exacting procedures. A more natural way of communicating non-trivial concepts would be to allow the user to indicate (i.e., point, illustrate, or change) his desires by a manual or analogue procedure rather than through a verbal or textual-encoding procedure. This section of the report will cover those new developmental devices that to some extent provide this type of communication between humans and equipment. At the present state of development these devices are experimental, expensive and require sophisticated logical equipment like a computer to operate the device. Although these devices are probably not yet feasible for mass application, they can be used on a research basis to further determine their requirements and merit for the instructional environment in anticipation of the time when such methods will be available on a production basis.

Cathode-Ray Tube with Light Pen. One of the simplest ways of allowing a human to communicate with equipment is to provide the opportunity of allowing him to point to or sketch ideas which he wishes to communicate. Two approaches presently in the developmental stage provide this opportunity. One is the work previously mentioned in part A of this chapter of allowing response input through a combination of cathode-ray tube display and an associated light-pen response device. This technique which has largely been developed at the Massachusetts Institute of Technology under the project titled SKETCH PAD provides a computer controlled cathode-ray tube through which pictorial or textual data can be presented to a user. The associated light-pen is a photo-sensitive device which responds to the light generated at an intensified point on a cathode-ray tube face at which the pen is pointed. The electronic circuits associated with the pen then amplify, shape, and transmit the response back to the computer which interprets this response in a manner that allows the computer to determine the position at which the light-pen was pointing. The use of a few other associated controls such as buttons or switches now allow the computer to determine what action is to be taken as a result of the detected response. For example, a button labeled "draw" may indicate that the computer should now follow the motion of the pen and present a line across the cathode-ray tube face corresponding to the path through which the user directs the pen. Other functions such as "erase," "move" or "rotate" may be indicated depending upon the application. The cathode-ray tube and light-pen constitutes, so to speak, the paper and pencil of the user; but as has been indicated, they possess extremely powerful properties not available to conventional paper and pencil in that the computer under program control can now manipulate the design as specified by the user. This intimate association of displays controlled by the logic of the subject matter and learner responses allows the student to investigate the subject matter in a way and at a rate not possible with other known approaches. Figure 3.12 indicated the operational components used with this equipment. Typical characteristics of present-day devices are an active surface area of about 10 inches by 10 inches with light spot location specifiable to about one thousand points per vertical and horizontal dimensions or a total of one million discrete points. The amount of line or graph that can be displayed without noticeable flicker is between four hundred and eight hundred inches, depending upon the technique of generation. Techniques of tracking or following the motion of the pen easily provide for a drawing rate between ten and one hundred inches per second.

Graphic Pattern Detection. Another approach toward graphic pattern detection is work being carried out at both Massachusetts Institue of Technology and the Rand Corporation on the detection of stylus motion through electrostatic (or electromagnetic) pickup and coordinate encoding. Figure 3.25 depicts the general approach utilized with this technique. A grid of horizontal and vertical conductors are printed upon a suitable substrate with the ends of these conductors connected to input wires in such a manner that a series of pulses applied sequentially to the input wires will create a uniquely coded sequence at any point of the grid. The stylus when held near a point on the grid will then electrostatically pick up the coded sequence of pulses associated with that grid point. For example, Figure 3.25 shows a grid containing seven horizontal conductors and seven vertical conductors with the horizontal conductors with the horizontal conductors connected to input wires *a*, *b*, and *c* as shown and the vertical conductors connected to input wires *d*, *e*, and *f*. For the stylus position shown in the figure, applying pulses sequentially to input wires *a*, *b*, *c*, *d*, *e*, and *f* will result in pulses picked up by the stylus at times corresponding to the time that inputs *c*, *d*, and *e* were pulsed. No pulses are detected at the times when *a*, *b*, and *f* are pulsed. As the stylus is moved from point to point a new code is obtained from the stylus depending upon its location on the grid. As was the case with the cathode-ray tube and light pen, additional inputs may be provided with this detector

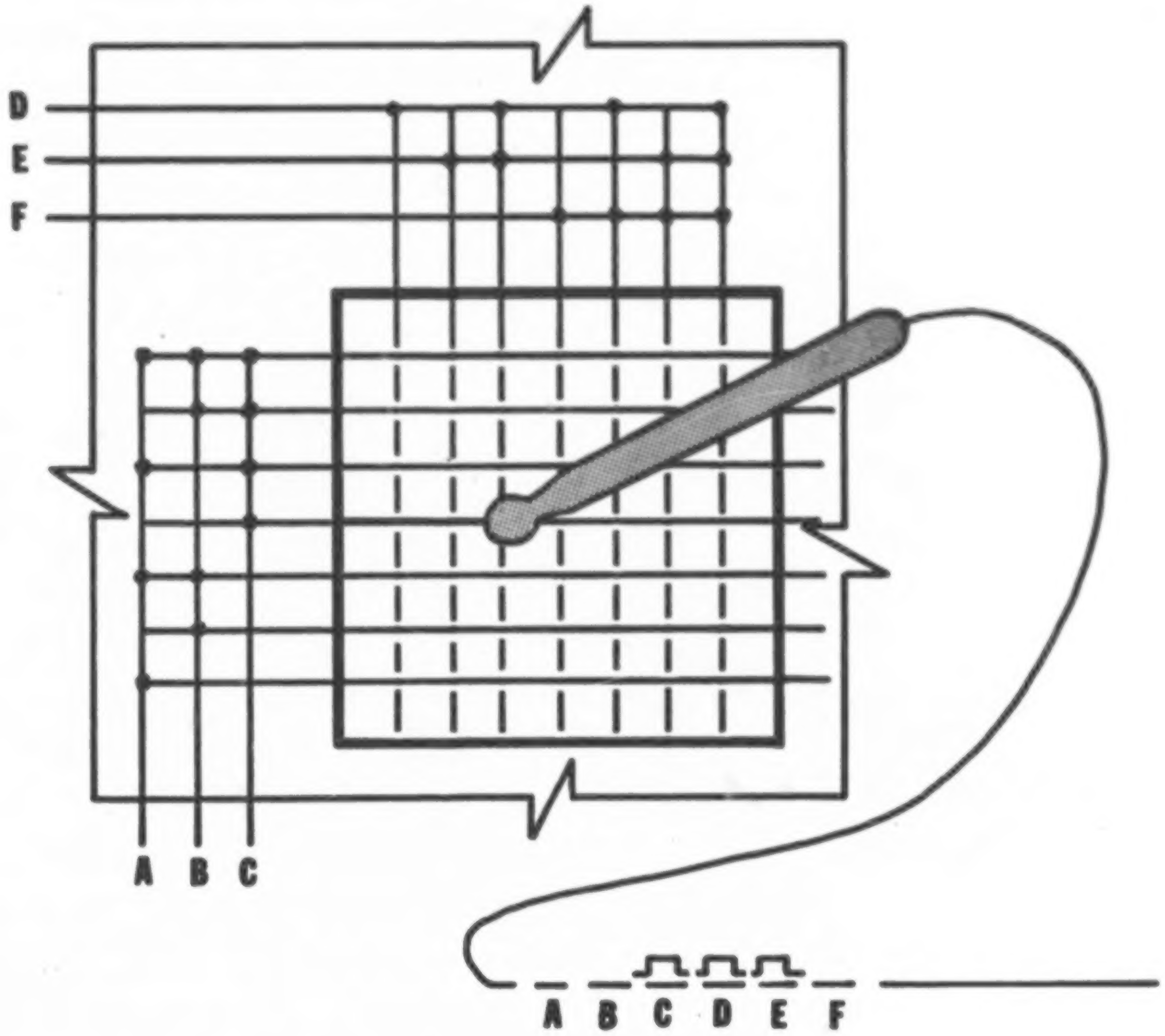
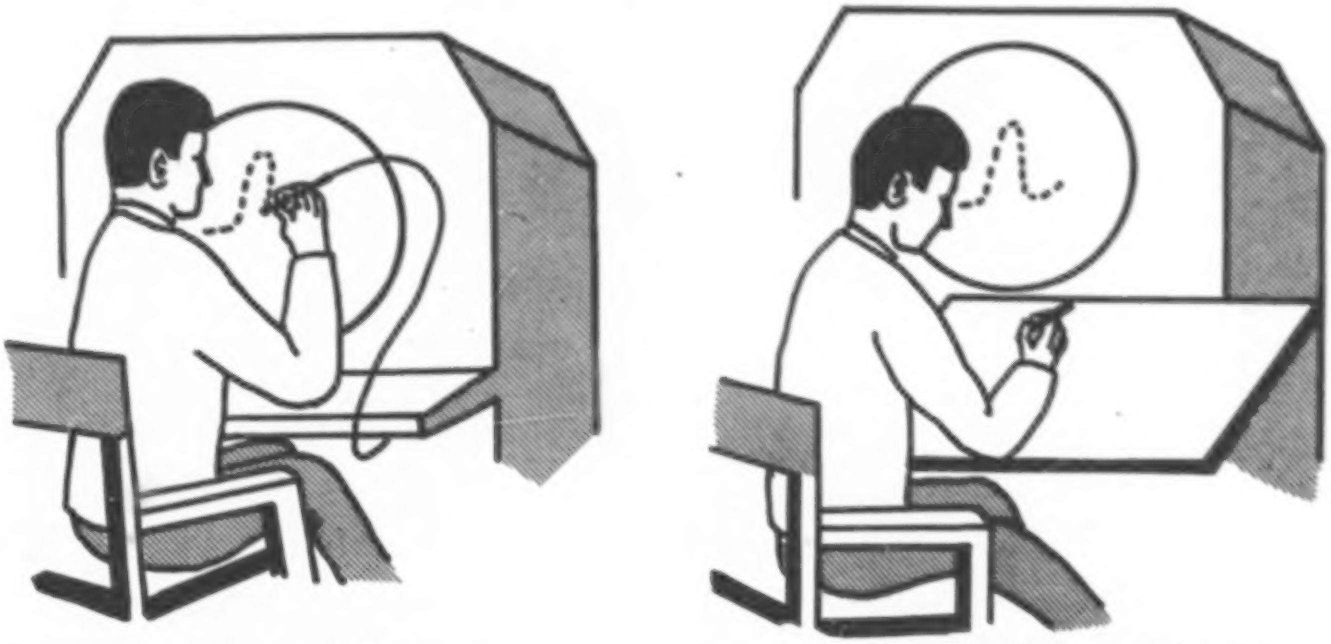


Fig. 3.25. Graphic Pattern Detector

to guide the program which is interpreting the input. For example, an additional switch perhaps located on the pen itself may indicate to a computer program that the pattern being detected should be displayed upon an oscilloscope or perhaps be processed in some manner different from that with an unactivated switch. An interesting technique demonstrated at the Rand Corporation was the use of a switch activated by pressing down on the stylus itself. With the stylus pressed down an associated display of the input pattern would remain permanently on an oscilloscope face; when a stylus was lightly held and the switch unactivated, the presented oscilloscope display was temporary and faded in a few seconds. This type of pattern detector obviously does not have the intimacy of display with response as that obtained with the CRT and light pen as shown in Figure 3.26. However, one interesting possibility with this type of input is that several stations may contribute to a common display on which each contributor can identify the location of his own pen. The light pen technique requires the pen be positioned over a lighted position to be detected



CRT LIGHT PEN STATION

ELECTROSTATIC GRAPHIC PATTERN DETECTION STATION

Fig. 3.26. Graphic Response Techniques

while the electrostatic pickup detection scheme can detect the pen in any position on the active surface. Thus, several users each operating at his own station but viewing a common display may contribute to any part of the display and to the manipulation of the display itself. Present indications are that the input resolutions of devices of this sort are about 100 lines per inch and a tracking rate of 10,000 positions per second.

Touch-Sensitive Display. Another approach analogous to that of the cathode-ray tube and light pen but not requiring the manipulation of a pen with an attached wire is that of a touch-sensitive display. Figure 3.27 depicts one possible technique of implementing this approach investigated as part of this study. A transparent material such as lucite is used to support a matrix of very fine wires. These wires are supported under tension in grooves cut so that normally the horizontal and vertical wires do not touch. When slight pressure such as finger pressure is applied at some point of the matrix, the horizontal and vertical wires come into contact

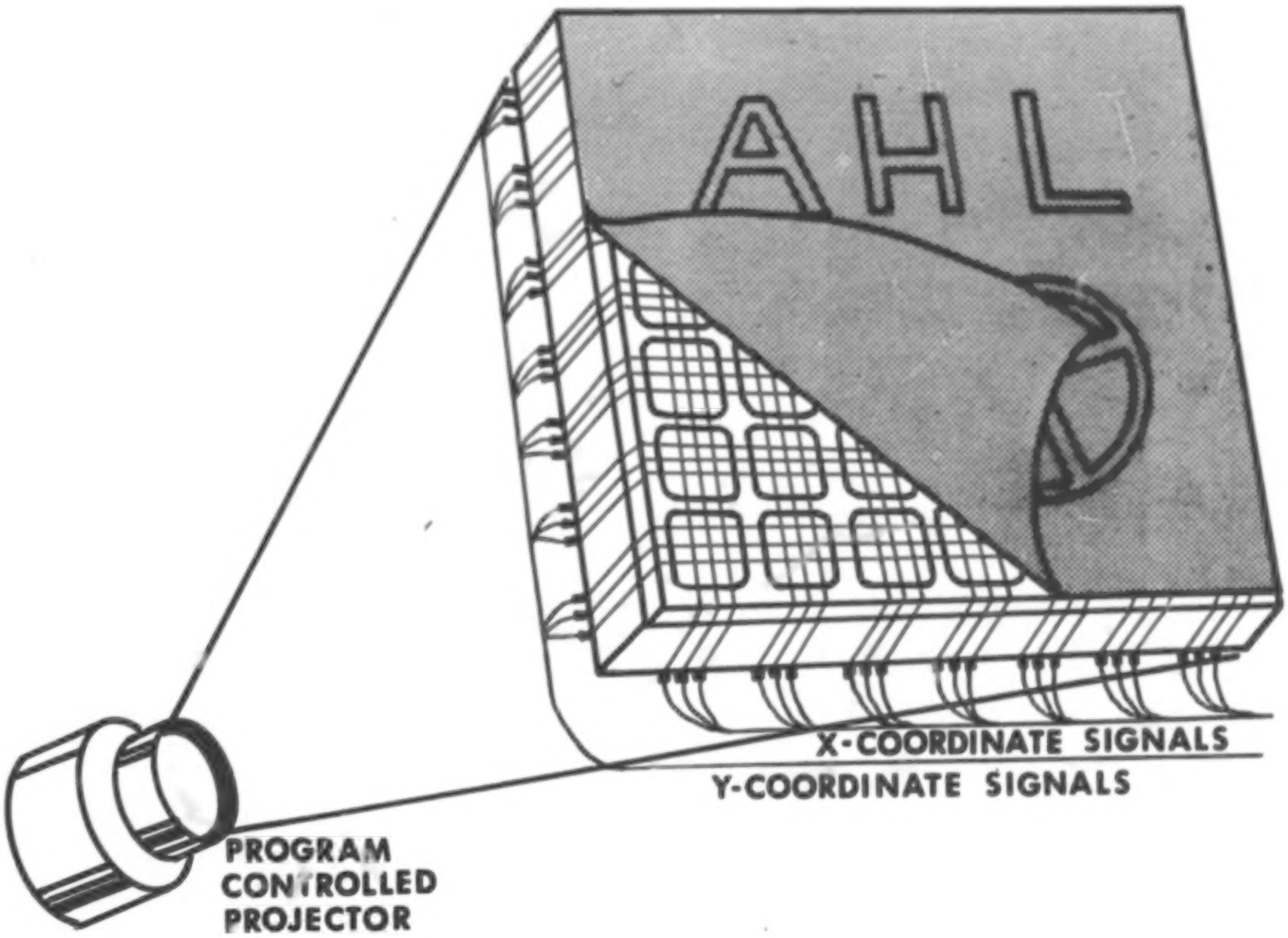


Fig. 3.27. Touch-Sensitive Display.

and the short circuit which is created can be electrically detected to indicate what portion of the matrix is being touched. By covering this matrix of wires with a flexible, translucent and light-diffusing sheet of material, pictorial information can be projected through the assembly which now acts as a back-lighted display which is capable of detecting finger pressure response that is uniquely associated with some portion of the display being presented. This method of approach, does not have the resolution of the cathode-ray tube, but for certain pedagogical situations, the approach may have adequate resolution and the advantages of technical simplicity. Signals from an assembly or device of this sort can be used as inputs to a computer program or some simple logic for selecting the next display to be presented.

Manipulation Board. Another response detector suggested by subject matter requirements for young children which appears useful to the educational environment is the "manipulation board" which is a surface capable of providing information concerning the identity and orientation of specific items located on its surface. This device would have the capability of providing information regarding patterns or arrangements of specific items such as children's blocks which can then be interpreted by associated equipment in accordance with a particular program. Figure 3.28 illustrates one possible approach towards the implementation of such a device. The surface is formed of a conductive grid which has embedded between each of its coordinates (each square cell) a pad of conductive material. Separate lead wires are attached to the grid and to each pad and brought out for external connection to some encoding or interpreting network. The device operates by placing specific items upon the surface that are capable of establishing a capacitive coupling between grid network and the pads. A driving signal applied to the grid is coupled to those pads that are covered by the specially constructed items. Figure 3.29 shows a block of non-conducting material that has been plated with conducting material. Each block or each block type must have a unique area of plated material on its surface and sufficient unplated area at the edges to prevent two adjacent blocks

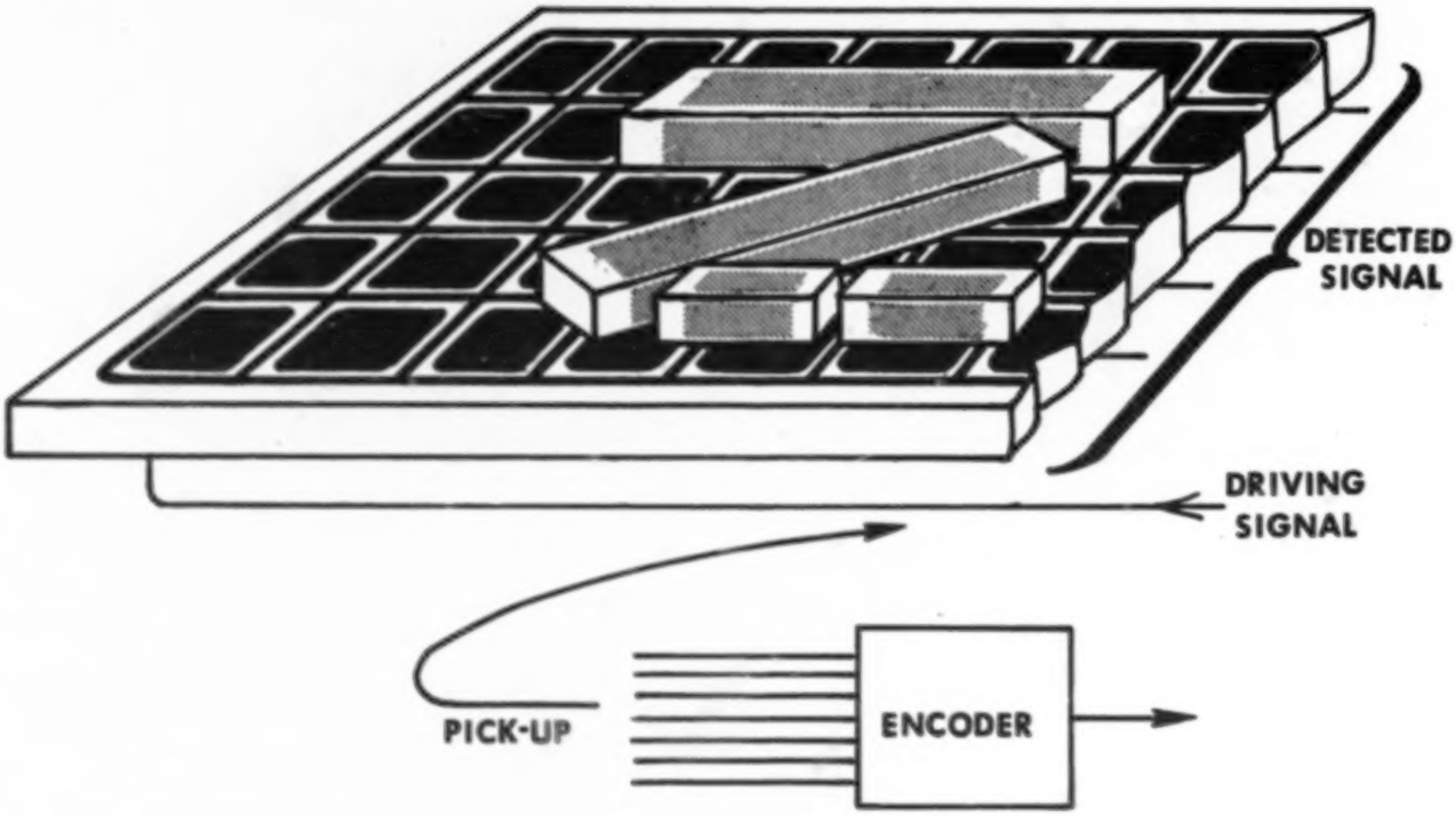

DETECTED SIGNAL
DRIVING SIGNAL
PICK-UP
ENCODER

Fig. 3.28. Manipulation Board.

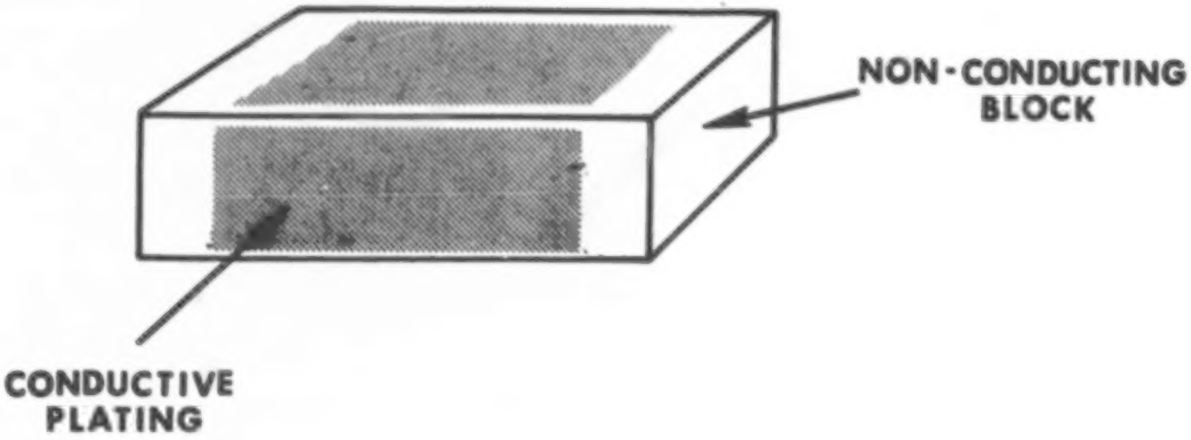

NON-CONDUCTING BLOCK
CONDUCTIVE PLATING

Fig. 3.29 Detectable Block

from appearing as some larger block. The number of activated pads which are adjacent then provide an indication of the block type and its orientation. The analysis required by an interpretive program to determine the item identity and location and the pattern composed of several items would be extensive. The rate, however, at which such patterns would have to be sampled is fairly low compared to present-day scanning and computation speeds. For example, a scan and evaluation every five or ten seconds would probably be sufficient to determine whether any significant change in pattern had occurred. It is also quite possible that with fairly young children and with large blocks (1 cubic inch or larger) the resolution of the surface need not be great, and the total number of detecting pads would not be an excessively large number. The geometrical configuration and the number of items that can be associated with a particular "manipulation board" is primarily a function of the board's resolution and the capability of the associated interpretive logic. Hence, the use of such a pad can be adapted to various subject matters depending upon what the items represent and programs associated with it.

Speech Recognition

Another pattern-recognizing response device has already been discussed in Part B under speech recognition. As discussed there, audio or verbal patterns consisting of words and sequences of words can be detected and compared against stored patterns as a means of determining response. The stored pattern is created by sampling a sequence of repetitions of the desired response and establishing the tolerance range or variation to be allowed in a detected response. Present day state of the art appears to indicate that small vocabularies (50-100 words) can be stored and detected with response accuracies in the order of 90 to 95% correct even when the user characteristics vary to some extent such as voice differences which exist between different individuals (Olson, 1964).

Device Application

The preceding paragraphs have indicated the scope and trend of some of prototype and experimental techniques being explored which can be useful as response-detecting devices. The devices discussed obviously do not include all conceivable possibilities with existing technology. Closed-circuit television, for example, may provide a valuable response detector where again pattern-recognition schemes may be implyoyed.

The use of experimental devices such as those mentioned above is presently expensive both in the equipment required and the programming necessary to effectively use them. The additional versatility that such devices provide the subject matter programmer, however, requires their consideration in conjunction with subject matter analyses as discussed in Chapter 2. The cost of these devices is also increased when they are used experimentally to study the learning process and include extra features which permit the manipulation of variables for study and the measurement of response characteristics of the learner. Those devices and methods that demonstrate improved instructional performance can then be developed on a production basis.

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CHAPTER IV

RESEARCH AND DEVELOPMENT

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Preface

The significant initial step to follow up the concepts discussed in the previous chapters of this report is to conduct research and development through a program of experimentation and feasibility studies. With respect to this step, Chapter IV presents the goals and tasks of such research, the special problems that can be investigated, the type of interface equipment indicated by subject matter considerations and instructional requirements, and overall considerations with respect to computer and instructional programming.

Part A

Principal Tasks

In order to be productive in implementing the concepts which underlie a student-subject matter interface, research and development would need to consider subject matter instructional problems, equipment design problems, and investigations of the learning process. Specifically, such research and development should explore the following areas.

Subject Matter Analysis

Subject matter analysis involves the study of subject matter display, response, and feedback requirements in order to determine appropriate properties of the learning environment, as provided by the interface equipment. Of particular interest here would be the extent to which close simulation of subject matter features and extensive provision for the manipulation of subject matter structure would enhance desired learning effects.

Instructional Analysis

The concern here is primarily with teaching techniques and student learning characteristics. In contrast to display and response features and their manipulation, which is the concern of subject matter analysis, the emphasis is on instructional procedure. The variables that must be studied in this category include such things as the display mode preferred by the learner, the order or combination of display and response modes that maximizes transfer, and the kind of error correction or response prompting that facilitates learning.

The Development of Prototype Lessons

Related to the above functions is the task of constructing model lessons using the capabilities of the interface. These lessons should provide exemplary segments of subject matter instruction and should be extensive enough to show long-range learning effects over a period of time more equivalent to school learning than a short-term experimental laboratory task.

Analysis of Learning Behavior

As a student proceeds through a lesson, the lesson can be designed so that basic learning experiments can be performed and so that a computer-based laboratory can pick off various measures of learning effects. These measures can include the degree of activity related to a subject matter stimulus in terms of the rate of student response, response accuracy, and response latency (latency of response in learning experiments has proven to be a very sensitive measure of learning which is difficult to measure without instrumentation which can detect the short interval of time between stimulus presentation and student response). Other measures of learning, such as frequency and type of errors and number of trials to a learning criterion, can be detected and readily processed for analysis. Experimentation can proceed by comparing two differently constructed lessons which vary along some dimension such as delay of feedback. It may be possible, however, on the basis of careful monitoring of student performance, to vary certain properties of the experimental material, depending upon the response characteristics of the learner. This can provide more dynamic control of learning effectiveness and provide more information about learning over a short period of time than is possible in a more static experimental situation. For example, it should be possible to vary, depending upon learner response, such properties of a learning sequence as the rate of presentation of stimuli, the length of a learning block, the amount and kind of stimulus change produced by a response, and the order of concepts. In any event, a computer-based laboratory can provide very detailed experimental data concerning human learning.

Equipment Analysis

Related to the above functions of the laboratory is the analysis of equipment characteristics for design purposes. This analysis requires careful assessment of the equipment specifications necessary for certain subject matter learning. The answers to such questions as how much fidelity is required in an auditory display, how much resolution is required in a picture, how much maneuverability is required for control-display relationships, and what degree of error must be detected, contribute to the development of equipment specifications which determine not only learning efficiency but economical production of the equipment itself.

Part B

Problems for Investigation

Basic Instructional Problems

The display, response, and monitoring capability of a research facility must permit a wide range of significant instructional problems to be investigated. Illustrative problem areas are described below:

Subject Matter Instruction at Early Ages. Present day norms for when reading instruction or instruction in numbers should begin are based on various conceptions of maturation and child growth and development. Recent studies (Tyler, 1964) suggest a re-examination of these concepts. Maturational norms have been postulated on the basis of what takes place in most existing teaching environments, but do not say what is possible under new circumstances. Many of the readiness requirements which apply to teaching young children refer to the difficulties the child has in making motor responses such as pencil marks or making fine visual discriminations. Appropriate manipulanda and displays may often serve to overcome these difficulties. If it seems desirable to teach certain subject matters, such as reading, at an earlier age than is conventionally done, an appropriately designed interface could make such learning feasible. A problem for study, then, is the feasibility of employing for instruction specially designed interface materials which utilize the kinds of responses and discriminations with which young children must begin. A conceivable development is the construction of a keyboard placed in the floor of a playroom so that the keys could be activated by the child standing on them. Many of the beginning relationships now taught to young children with a typewriter may be taught to younger children in a large playroom setting.

Studies in this problem area will consist of designing instructional lessons appropriate to the world and abilities of the preschool child. The development of such lessons will require (1) detailed assessment of the kind of display and response characteristics that maintain the interest and self-sustained activity of the child and (2) the scheduling of interrelated, individual activity with an instructional interface, peer activities, and student-teacher activities.

The Parameters of Individual Differences. A long-standing datum of psychology is the fact of individual differences. The varied individual backgrounds that students bring to school have also been recognized by educators for a long time. However, in educational practice the fact is more often talked about than acted upon. Increasingly, however, the significance of individualization of instruction is being recognized (Henry, 1962; Goodlad & Anderson, 1963; Suppes, 1964). While the development of computer-based instructional systems can permit increasing individualization of instruction, an especially significant area for study is the relationship between measures of individual differences and conditions for learning. The success of aptitude test prediction depends upon the correlation between measured behavior before learning and final level of performance after learning. However, little systematic information is forthcoming from pre-learning measures about how instruction should proceed in order to optimize instructional effectiveness. Detailed knowledge is required about the relationship between the present characteristics of the learner and the appropriate instructional environment required to permit him to attain educational goals. Research on this problem requires the development of a theoretical structure for integrating aptitude measurement with learning theory and experimental analysis of the components of intelligence and aptitude in terms of their functional relationships to various kinds of learning. A direct approach to this area can be made with computer technology by using the computer to maintain long-term records of the progress of individual student learning and fitting the learning curves obtained to theory-based mathematical models. Since stable, longitudinal data will be obtained for each student, it seems possible to develop models of learning for various kinds of instructional tasks in which certain parameters of the model represent systematic individual differences. This can be done in the same way that certain parameters, in present-day applications of mathematical models to the description of learning phenomena, represent the effect of experimental variations in conditions of learning.

Testing and the Assessment of Pre-instructional Behaviors. In the light of current thinking about the educational process, the assessment of pre-instructional performance and the conduct of instruction must become more integrated procedures than they have been in the past. With this in mind, a significant problem is the investigation of the units of such interface devices as described in this report for testing and assessment functions, such as: individual testing, e.g., using the Stanford-Binet to obtain an IQ measure; the identification of learning preferences; and the assessment of problem-solving approaches to subject matter. It is commonly reported that individual testing, especially with young children, produces more reliable scores than does group test information. To a large extent this is a function of the adaptability of the examiner in deciding upon the appropriate test levels and making decisions about items on which to continue or discontinue testing. It seems worthwhile to investigate the possibility of an automated testing device. Test constructors have indicated the desirability of sequential testing procedures whereby an individual is tested and then shifted to new levels if appropriate. It seems possible for a device to present test items in a variety of modalities, to sense the characteristics of the testees response, and to make decisions about the next item to be presented.

A related area for investigation is assessment of the methods by which a learner prefers to proceed through an instructional task. Such assessment can introduce a significant aspect into the individualization of instruction. Most present-day practices which attempt to individualize instruction (such as ungraded classes and programmed instruction) individualize primarily along one dimension, that of learner rate, where provision is made for some learners to proceed at paces different from others. Individualization in a broader sense should involve other dimensions of the educational process, such as differences in kinds of material that a learner likes to work from, self-initiated or highly directed activity, and his preferred study methods. It is possible that problems can be set into a computer-based interface, and the student's interaction with sets of problems can indicate such preferences as whether he learns more rapidly with a certain kind of material by listening rather than reading or by working with diagrams or words. As a research task, these preferences can be correlated with test measures; for instructional purposes, they can be used to prescribe certain kinds of lessons, at least in the early stages of learning.

The pedagogical implications of the work of Newell and Simon (1961) on the simulation of cognitive processes require exploration. One of these possibilities involves the assessment of learner behavior in relation to the models programmed into the computer. The approach would be to establish an optimal strategy for the solution of certain kinds of problem structures, and to compare the problem-solving attempts of the student with such problem-solving behaviors as have been identified (e.g., Simon & Simon, 1962). The determination of mismatch between the student's problem-solving model and an optimal problem-solving model can be used for experimental study and for instructional purposes in teaching problem-solving behavior.

Optimal Steps in a Learning Sequence. In the course of an instructional sequence, the particular characteristics of a subject matter stimulus presented to the learner determine his response to that particular learning step. The stimulus material may be too difficult in the sense that it contains too many items of information or it assumes mastery that has only been partially attained; on the other hand, it may be too simple in the sense that it requires a trivial and repetitious response or provides little reinforcing stimulus change. Experimental evidence has also indicated that in learning lists of items, a certain size of blocks of items provides more optimal learning and that it is not always the smallest block that results in the most efficient learning (Suppes, 1964). In typical linear programmed instruction sequences, the next learning step in a sequence is based upon an empirically derived average difficulty level for a group and is rarely optimal for the individual learner. What is required of any individual learner is some means of anticipating the optimal learning step for him, based upon knowledge of his learning characteristics to that point. Studies along these lines would be of two kinds: (1) the determination of runs of subject response measure, latency, number of errors, amount of correction required, etc., that permit some prediction of the characteristics of the next learning step, and (2) some method of permitting adjustment by the learner of the characteristics of the next step in a sequence.

Overt Error Correction. The influence of student activity involved in the correction of erroneous responses has been an inadequately investigated aspect of student learning. In the experimental laboratory, the emphasis on the effects of positive and negative reinforcers following the occurrence of a response has been emphasized, and in motor skill training, corrective feedback has been studied (Bilodeau & Bilodeau, 1961). The effect of correction in verbal and cognitive learning has received less attention (Angell & Lumsdaine, 1963; Bower, 1962; Suppes, 1964). It seems probably that the effects of overt correction function in a way similar to the reinforcement of correct responses; indeed, some experimenters have assumed that this is the case (Bower, 1962). The immediate and overtly displayed correction of errors can be implemented through appropriately designed interfaces, and the effects of error correction and investigation of optimal conditions for its use can be studies.

The Discovery of Reinforcers. The operation of reinforcement refers to the fact of behavior that certain products or contingencies of an activity serve to influence the further course of that activity. However, the specific products or events following an activity that serve as reinforcing stimuli need to be discovered for different situations and for different individuals. For some learners, knowing that they are correct may be reinforcing; for other learners this may be trivial, and the primary reinforcing event for them is to be presented with a more challenging problem or to be allowed to leave the situation. An adaptable learning environment can provide a wide range of contingencies in the course of subject matter learning so that the particular contingencies which are reinforcing to a particular learner can be determined. For young children, some sorts of objects may be more reinforcing than others, and the use of various sensory modes may be differentially reinforcing. For older children, different subject matter themes or different kinds of pictures may have different reinforcing effects in the course of learning. Studies along these lines can be made to investigate individual differences in effective reinforcers and also to investigate improvements in learning efficiency as a function of the adjustment to these individual reinforcement characteristics.

The Reinforcement of Curiosity and Exploratory Behavior. As indicated in Chapter I, an extremely significant area for study is the development and maintenance of curiosity and exploratory behavior, using stimulus change as a reinforcer and incentive motivation. The responsiveness of the kind of environment suggested in this report for stimulus change can be quite useful for studies in this area. There are many questions that need to be studies, both with respect to the definitions of curiosity and exploration in various subject matter tasks and with respect to the kind of learning situations which teach these behaviors. Techniques for reinforcement and shaping of exploratory behavior need to be investigated. As has been indicated in Chapter I, of special interest is investigation of the properties of stimulus change as a reinforcing stimuli. This involves such related questions as the effects of different magnitudes of change, satiation effects, and reinforcement schedule properties.

The Teaching of "Aptitudes." Conceivably, a pre-school curriculum for children would not feasibly be the extension of formal subject matters down to younger ages. What might be considered is the teaching of behaviors which are more generally classed as aptitudes, assumed to be formed while the child is very young; for example, the ability to make fine pitch and rhythmic discriminations which are part of a musical aptitude. A research program along these lines would attempt to analyze in detail the prerequisite skills and concepts (similar to the learning-set analysis of Gagné, 1962) necessary for learning more complex behavior, such as beginning phonic concepts or beginning number-object relationships. Careful identification of the performances prerequisite to these accomplishments would allow them to be taught by means of an appropriate learning environment.

Experiments With Play, Freely Structured and Manipulative Activities. A long-standing research methodology in the study of child development is the observation of play and freely structured activities (Wright, 1960). This is somewhat related to the point above of assessing learning preferences. It seems possible to combine the area of observational child study with some of the rigor of laboratory experimental study (Bijou & Baer, 1960) by use of a computer-controlled environment. A wide range of stimulus and response possibilities can be provided, such as particular gamelike stations or large area floor and wall manipulanda. This environment could provide playroomlike variety and also automatic record keeping of children's responses and manipulations. A specific example for a child about to begin the study of elementary arithmetic concepts is observation through sensing devices, (e.g., the manipulation board as discussed in Chapter III) which detect the characteristics of his manipulations of objects, that is, the orderliness and complexity of his arrangements.

This latter point, the study of object manipulation, seems especially significant since object identification and manipulation and similar tactile experiences underlie a large portion of kindergarten readiness activities, and educators have emphasized their importance for many years. Beyond "readiness" activities, there has been for some time the teaching of arithmetic concepts through the manipulation of blocks (Gattegno, 1963). More recently, Bruner has discussed problem solving by children in terms of the use and study of manipulative activity (Bruner, 1964a; Bruner, 1964b). A direct approach to the study of manipulative learning and the use of manipulative activities in concept learning and problem-solving activities may be to employ sensing devices such as those indicated in Chapter III. If, with the help of these devices, experimental situations could be devised, studies in this important area of the manipulative responses of children would be accelerated.

Reduction of Abstraction Requirements and Performance Clutter. It seems possible with the aid of innovative interface devices to present subject matter to the student and have him manipulate it in a way which reduces the "inherent" difficulty of the subject matter. "Difficulty" however, is a non-specific word and needs to be defined in terms of some property of task behavior. One aspect of difficulty may be that the subject matter task involves degrees of abstraction and concept formation by the student. Part of the difficulty of teaching abstractions is that they are remote or that they are non-concrete in the sense that higher-order concepts and abstractions become increasingly less tangible and refer to ideas and the relationships among things rather than to the things themselves. Instruction in a subject matter might be made less difficult if certain of the abstractions involved in it can be made more concrete; the decreased demand might then permit the student to grasp more complex abstractions. For example, in the teaching of functional relationships in mathematics, instruction in a conventional classroom environment might require that the student conceptualize how the slope and rate of change of a curve vary with different constants in an equation; in calculus, the student is asked to conceptualize the meaning of the first and second derivatives of a function. It is possible to arrange cathode-ray tube displays in which the student can directly manipulate parameters in an equation and observe the consequent changes in the function the equation represents (Licklider, 1962). As another example, in teaching factor analysis, it should be possible to allow the student to manipulate vectors in three-dimensional space as part of an introductory lesson to this topic. In this sense, an appropriate interface can reduce the cognitive requirements involved in learning. Perhaps the attempt to make abstractions more overt can facilitate study of the ways in which students handle the abstractive process.

Another source of difficulty in classroom learning is that the layout of a student's work often places demands for keeping tract of his working process either because he must solve a lengthy problem, or he must record his progress so that he has stored notes to which he can refer in the course of solving the problem. For example, a young child may be wrong in working a long division problem or solving a word problem in arithmetic because his work is untidy and he has difficulty in keeping track of it or referring to it. At least in the early stages of instruction it should be possible to facilitate learning by devices which can record student efforts in an organized fashion. Development of a human-engineering nature can serve to study possibilities for aiding instruction along these lines.

Competitive and Cooperative Instructional Systems. The use of cooperative and competitive instructional lessons in which students work with one another has interesting possibilities for study with a computer-based interface. Following the lead of efforts in computer simulation employed in universities for studying such situations as corporation management, so-called "business games," it should be possible to develop procedures applicable to elementary-level teaching, as has been suggested in a review by Bushnell (1964). Arithmetic problems and word problems can be displayed to a group of students who work at individual stations in order to manipulate a group display. Each student can be given a particular problem-solving function or they can challenge each other by setting problems into their stations for the others to solve. The recorded responses can be used both as a means for guiding instruction for the participants and for analyzing group learning by the researcher. Some unexpected effects of significance for learning theory have been described in studies of group training by Egerman, Klaus, and Glaser (1962). This study points out the necessity for a careful analysis of group instructional situations in which the group is oriented toward a problem solution because certain group structures may result in decremental effects for some of the learners involved.

Equipment Development Problems

In considering those components of the laboratory that may form a part of the interface between the student and the subject matter, conventional devices such as keyboards or slide projectors and movies are assumed to be available when required by a particular experiment. These devices may require modification in order to be adapted to the particular system being developed; however, such modifications would be principally technical adjustments for the linking together of different items of equipment whereas the functional operation of such devices would be similar to that normally defined for unaltered devices. For example, typewriters or typewriterlike devices are often used as computer input devices and although the operation of such typewriters is uniquely controlled by the computer, the actual manipulation of the keys and the responding of the typewriter to such manipulation is similar to that of a non-computer controlled typewriter.

The interface devices discussed below are special devices that appear to be uniquely suitable to the instructional process as has been described in this report. Such devices do not exist other than in a prototype or developmental state, and part of the research and development envisioned would be the further specification and verification of the suitability of such devices and their engineering specifications. The guide lines given under the items listed are those hypothesized to be suitable from a consideration of the subject matter requirements and from what appears to be technically feasible. Further research and development may show that the requirements of devices such as these can be reduced in some areas and may require tightening in other areas.

Object Manipulations Devices. In certain subject areas like arithmetic or spelling it is felt that the ability to dispense and collect items bearing relevant symbols such as the letters of the alphabet or numerals would be valuable. Devices similar to coin-changing machines which would operate under the control of a computer would thus be a component of the interface equipment. The items dispensed and collected would be coinlike plastic discs having embossed characters or symbols. A set of 32 possible types of discs that could be uniquely identified in a collector or dispensed under program control is desirable. Some variations in disc diameter could be accommodated although it would appear more desirable that discrimination of the discs either be made on a weight basis or through notched edges or some other such means and that the variation of disc size be limited to two or three classes.

Another device used for the manipulation of objects is that described as a manipulation board in Chapter III. This board which would have the capability of detecting identity and orientation of a specific set of objects would be used in those subject matters where the character and relative relationship of different items is of significance. The active surface of a device of this sort should be approximately 2 feet square with the smallest object associated with the device in the order of 1 inch on a side. The set of different objects that can be discriminated by the board should be of the order of 10 or 12 for any one lesson and the orientation of such objects should be resolvable to within 15° or less.

Graphic Devices. One of the more manipulable displays is that which shall be referred to as "constructed displays" and was described in Chapter III under the general heading of "Cathode-Ray Tube Displays" with associated light-pen response detectors. Such displays, when associated with a suitable computer, provide the subject matter programmer with the opportunity of accommodating display configurations that will not be constructed until the program is in actual operation with the student. That is, the programmer need not consider and make provision for large sets of displays in anticipation of a particular response by a student, but rather the program can be written to analyze a student's response and then compute or construct the display required. This ability provides a degree of manipulation of subject matter symbols to an extent not possible with any other type device presently known. Guide lines of such a device for the instructional environment would include a working area of approximately 10 inches by 10 inches. Black and white patterns are adequate although two or three levels of gray tone would give additional meaning to the displays. Since this display requires extensive service by associated computers if much information is being presented, it will probably be necessary to add buffering devices which store non-dynamic information which is being presented on the display. For example, if the auxiliary storage devices such as electronic storage tubes or magnetic cores were used to contain background information and the computer supplied only that information which had the appearance of continuous motion on the display surface, the requirements on the computer for a particular display could be significantly reduced. For such a display, the computer-generated portion might reasonably be limited to the order of 20 or 30 linear inches of display per station.

Another device, referred to as the graphic pattern detector in Chapter III, can be used in much the same manner as that described above as "constructed-response device." In this system, the student's response is on one device whereas the results of that response are indicated on a separate display visible to the user of the input device. This device, as mentioned in Chapter III, can be useful where two or more students may be responding to a common problem and sharing one common display media. Such an arrangement could conceivably be done with the "constructed-response device" described above, although the arrangement using graphic pattern detectors probably has economic advantages in operation. Another advantage of the graphic pattern detector is that its operation is such that the position of the associated pen can be detected no matter where the pen is placed on the detector; with the cathode-ray tube and light pen, a user generally must initially locate the pen by starting at a location already illuminated or one which has some symbol or character being displayed at the moment. Instructional guide lines for a device of this type would be a 12 inch by 12 inch overall size of active area, an ability to resolve character sets or symbols one-quarter inch or larger in height, and an operational speed that would allow it to follow normal handwriting speeds.

Another type of display described in Chapter III, which contains the feature of intimacy of display and response characteristics is that referred to as the touch-sensitive display. This is a device containing many of the features of the devices described above in that the student associates his responses directly with the display being presented. The device, however, would not have the resolution the above devices contain and probably would not have associated with it as large a set of possible displays. The advantage of this type of device, on the other hand, is its relatively light loading or demands on associated computing equipment while still containing a large set of possible responses. When used with projection equipment, the displays could contain all the advantages, such as color and good resolution, of film projection devices. Instructional guide lines for such a device would indicate an active area approximately 12 inches by 12 inches with individually touch-sensitive areas one and one half inches square (64 total areas). The requirement for the associated visual display device would be access within one second or less to approximately 100 different displays.

Auditory Devices. For auditory displays, the principal requirement is that of short access time to a reasonably large library of messages. For research purposes, it is felt that devices providing access of less than one second to about 100 messages, each message being of the order of eight to ten seconds in duration, would be suitable.

The recognition of audio sounds is one of the more difficulty techniques of all those that have been discussed. Its apparent usefulness, however, to the instructional environment would indicate that research with existing techniques should be encompassed in order to explore the possibilities and merit of even a small set of recognizible sounds. For instructional purposes, therefore, the guide lines proposed are that the equipment be able to distinguish between 25 to 50 unique sounds of about one second in duration and that the recognition ability encompass a range of voices. For example, the set might include such sounds as letters of the alphabet, numerals, and perhaps standard phrases such as yes and no or plus and minus. The voice range to be accepted can be limited to male or female voices within an age span of three to four years. Since neither the student's response nor the recognition ability is accurate 100% of the time, an alternate stimulus for an unrecognized response might be "please repeat your answer." A device which could correctly recognize proper answers 95% of the time would seem satisfactory; this capability seems to have been achieved in certain instances for small character sets (Lesti, A; Olson, H. F., 1964). An additional, and probably necessary, requirement is that the character set utilized at any one time could be changed from lesson to lesson.

Part C

Support Tasks

A research and development project that encompasses the scope of student-subject matter interaction discussed in this report will require a major effort to implement and conduct. The project must have the continuity and range of subject material that will provide meaningful evaluations of both subject matter structure and the interface components being developed. In order to implement a project of this type there will be subsidiary areas of work that must be accomplished so that the main stream of research can progress with adequate support. Although it has been generally assumed throughout this report that the logical capacity of a digital computer and associated special equipment such as audio devices were available where needed, it is recognized that the implementation and use of this type equipment will involve research and development of its own. It is the intent of this section to indicate just a few areas not discussed elsewhere in this report that will require serious consideration if the projected research and development is to be successful.

Computer Programming

The effective use of interface devices will generally require an associated data processing or logic capability equivalent to that obtainable through the use of digital computers. The operation of devices such as the manipulation board described in Chapter III can involve elaborate computer programs of detection and pattern recognition which are essential to their operation as well as to the manipulation of the subject matter involved. Where several devices are operating on a real-time basis, time-sharing and multiplexing procedures must be encompassed within the operating system that are compatable with the instructional requirements of the subject matter as well as with the efficient use of the equipment involved. Techniques of time sharing and multiplexing are being developed in other fields but their applications to the instructional environment must be investigated, and any requirements unique to this environment encompassed within the procedures.

In order to evaluate the devices and procedures under investigation, field tests and laboratory studies involving many hours of student learning need to be prepared and applied under specified instructional conditions. The generation of such material is generally a time-consuming task involving much labor and field testing. In addition to the specification and development of the subject matter itself, the implementing of such material on a computer or related device so that it can be presented to the interface quickly is a major undertaking and requires much training, practice, and refinement before usable programs are generally available. To date, there are few aids such as programming languages to assist in the writing of subject matter programs for computer presentation. The specification and development of such aids, however, is probably a requirement before significant amounts of subject matter programs can be implemented on computerlike devices.

In addition to the programs and procedures for the operation of interface devices and for the presentation of subject matter through such devices, there are auxiliary or administrative programs necessary for the data-gathering and analysis task associated with the investigation of variables influencing learning and the evaluation of techniques under investigation. The programs may be common to several areas, but they will probably require continuous revision as the value of different measurements are better understood.

Auxiliary Facilities Required

Many, if not all, of the facilities and devices that have been discussed in this chapter will require auxiliary equipment for its operation. For example, the film projectors would probably need to be supplemented with cameras, film development and splicing and monitoring means in order to facilitate the research effort. Sound equipment would require recording and measuring facilities; in general, all equipment would require sufficient maintenance and operating personnel.

Measurement and Criteria

Progress in any field is enhanced as meaningful criteria and measures of performance are established. The establishment of such criteria as standards generally comes from a period of usage and the general acceptance by an involved population. Hence, such standards and measures are not normally available in the early formative years of a new technology. In the areas that have been discussed, most technologies are new and few widely accepted standards exist. The development therefore in all areas will have to proceed without the benefit of bench marks or guides, and a major contribution of work in this area can be these definitions and rules that may someday be accepted as criteria and measures of performance.

Research Environment

With regard to the layout of a research environment, it would appear that at least two different types should be provided. Oneeof these would be designed for individualized study. In this type, the student would be surrounded only by components of the interface equipment, and the environment would be such that he would be free from distractions or other influences outside of those associated with the subject matter presentation. Such an environment would require between 50 and 100 square feet of floor space and should be acoustically shielded from outside noise and interference. In some instructional situations, it may be desirable to have either an observer or tutor in the same area with the student undergoing individualized instruction. For these purposes, provision should be made to accommodate a second individual with room for note-taking or such activity as may be desired by a tutor.

The interface components contained inaan individualized environment would to some extent depend upon the subject matter being presented. As these layouts are basically for the purposes of research and development, it is necessary that some means of indirect observation of the student be provided; for this reason either one-way viewing panels situated in one wall of the area should be provided or provision made for closed-circuit television to monitor the activity of the student.

A second layout would be a larger area capable of accommodating from five to ten students to be used for research in the areas of cooperative instructional systems or general group instruction activities. This environment may contain equipment similar to that used in the individual stations although it may be operated and utilized in an entirely different manner. On the other hand, there will probably be need for equipment such as large displays that are visible to all members of the group or tables large enough for the entire group to work around. Depending upon the subject matter being presented, the interface components directly manipulated by any of the students may be provided on either an individualized or a group-shared basis. Since different subject matters may require grossly different configurations of equipment, one of the specifications of such an environment should be an ample number of electric outlets and equipment connection points such that a maximum amount of flexibility in equipment configurations is possible. As was the case with the individualized environment, adequate acoustical shielding should be provided to present disturbance from outside noise, and provision should be made for adequate monitoring or viewing of the student's actions.

As has been indicated throughout this report, most of the interface equipment and subject matter considerations have assumed the existence of sophisticated, logical equipment such as a digital computer to be available as required. Each such laboratory environment, therefore, would be provided with adequate ducting for access to a computer located elsewhere and to such other items of equipment as sound-reproducing or detection equipment, power supplies for specialized interface devices, and such other equipment as may be necessary to the function of the laboratory area itself.

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APPENDIX

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Part A

The Student-Subject Matter Interface in Special Education

A. Edward Blackhurst

It is in education of the handicapped and gifted that the flexibility and versatility of the interface concept can be fully demonstrated and applied. Special education is concerned with exceptional children--those who deviate mentally, socially, and/or physically from average children to such an extent that they require special treatment and services to develop to their full potentials. These children comprise about 12.5 per cent of the school population (Kirk, 1962). The general educational objectives for exceptional children are the same as those for average children.

This appendix is designed to apply to special education some of the concepts that have been previously advanced. A rationale will be proposed for the application of the interface concept to the blind and partially seeing, the cerebral palsied and orthopedically handicapped, the deaf and hard of hearing, children with behavior deviations, children with learning disabilities, the mentally retarded, and the mentally advanced. Considerations will be given relative to the programming of information and various physical designs of the interface. Certain problems will be delineated that could possibly be ameliorated through the application of various types of interface devices.

The Visually Handicapped

Visually handicapped children can be generally described as those whose visual deficit, after correction, interferes with learning. For educational purposes, two major categories are common: (1) the partially-seeing, whose vision can be corrected to such an extent that ink print can be employed for their education; and (2) the blind, who cannot use vision to acquire education.

Current educational materials for seeing children are adapted for the partially-seeing in the form of large-type printing and/or through the use of low-vision aids. Since there is no evidence to support the notion that partially-seeing children differ from seeing children in educational achievement (Nolan, 1963), it can be assumed that educational programs for seeing children could be modified, as suggested above, through the use of the interface and be useful with the partially-seeing.

The interface incorporating the cathode-ray tube could provide a means for the magnification of materials. Materials of instruction could be programmed in such a fashion that the student would immediately be able to control the size, contrast, and brightness of the image to fit his individual needs. Conventional instructional materials would receive wider usage than at present simply by televizing and enlarging them. This would enable the student to read most books with a minimum of difficulty. Any aural programs for normal children could be used without modification.

Careful consideration should be given to the physical aspects of the interface itself. For example, green chalkboards are recommended for the partially-seeing. It may well be that reading materials should be projected in negative on a green background rather than the conventional "black and white" image. Children with severe visual limitations may need to be quite close to the interface console. The display mechanism, then, would have to be adjustable so that the child could choose the viewing angle at which he is most comfortable. The console itself should be of a light, neutral color with a dull finish. If the console consists of a keyboard and viewing screen, it may be necessary to mount the keyboard on either side of the screen to allow the child to get close to the screen without hindering his ability to operate the keyboard. External lighting should be carefully controlled for those who are glare-sensitive. Lighting controls, which would be operated by the learner, could be built into the interface console.

Instructional programs for the blind will of necessity be aural, tactile, and olfactory in nature. Enc and Stolurow (1960) have shown that materials presented aurally can be comprehended at speeds faster than the average oral-reading rate. Information could thus be "compressed" and programmed on audio tape. An automatic selection device could be constructed which would enable the student to make selections of appropriate materials and regulate the rate for play-back. A large variety of programs could be made available by providing a central tape library and broadcasting station. Each student would be provided with a receiver and earphones. These programs could be used individually; or entire classes could use them in much the same way as they would a radio broadcast.

Reading instruction could be programmed on a computer-operated braille-writer. The student would be presented with a braille stimulus to which he would respond orally. Aural reinforcement or correction would be given with the student making the appropriate corrections as necessary.

Punched tape that is phonetically coded activates the keyboard of a stenotype machine that has recently been developed at the Massachusetts Institute of Technology (Medical Tribune, 1964). A blind person can be taught to "read" at speeds of 300 to 400 words per minute by feeling the movement of the keys with his fingers. Once the learner has become proficient in the operation of this device, conventional programs requiring reading could be applied to the blind.

Mathematical concepts are most difficult for the blind to learn. The abacus is typically used in teaching arithmetic to the blind. Perhaps programs could be developed for its use. A modified Cuisenaire program could be structured with the manipulation board for instruction in algebra and geometry. Equipment-controlled three-dimensional models would also be of value. Blind children could respond to the programs either orally or by using the typewriter. In fact, instruction in the use of both the braille-writer and the conventional typewriter would prove amenable to programmed instruction.

The blind depend to a large extent on olfactory cues when traveling from place to place. A device that emits different odors could be used for training in olfactory discrimination. This would be a valuable adjunct to mobility training since the student would be able to experience many different olfactory sensations in the controlled environment of the classroom or training area.

Devices designed for teaching auditory discrimination would likewise be valuable for training in readiness activities and mobility.

Parts of the interface, such as switches, that the blind child must manipulate would have to be either labelled in braille, be of various shapes and sizes, or be constructed in such a manner that auditory cues are made available in the form of click stops.

The Cerebral Palsied and Physically Disabled

For purposes of this discussion, the cerebral palsied and physically disabled are grouped together since their educational problems are related to the physical aspects of the interface, even though they are two entirely different disability groups that require separate educational considerations. Programs discussed elsewhere in this report could be applied to these groups; however, adaptations will be necessary in making provisions for manipulations of the interface and for overt responses in cases in which an oral response is impossible.

In cases of bilateral amputation or where the learner has no use of his arms and hands, it will be necessary to design the console in such a manner that it can be manipulated by the feet, toes, or other parts of the body. Photo-electric cells could be utilized so that responses could be made by moving the head to break a beam of light.

Stevens[1] has suggested the possibility of a specially designed electric typewriter. A revolving wheel on which different symbols are inscribed could be connected with an electric typewriter. For example, the quadraplegic could hold a triggering mechanism in his mouth. When the appropriate letter on the wheel appears below an indicator, the learner could activate the typewriter by applying pressure with his teeth on the triggering mechanism. This device could also be used by those who are less severely disabled by activating the triggering device with any functional part of their body.

Due to poor muscle coordination, children with cerebral palsy may have extreme difficulty manipulating various types of switches, buttons, and knobs that would appear on the interface console. It is suggested that response mechanisms take the form of recessed push-buttons. The child could then locate the appropriate button, hook his finger over the edge of the hole, and depress the button. This would eliminate inefficient motions which might result in the activation of the more conventional types of switches thus recording an incorrect response. This technique is similar to that which has been successfully used to enable cerebral palsied children to use the standard typewriter. Templates are placed over the typewriter keyboard to reduce the possibility of the child inadvertantly depressing the wrong key.

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[1] Godfrey D. Stevens, personal communication

The Deaf and Hard of Hearing

Educational provisions for children with auditory disabilities are dependent on their ability to communicate. Two educational programs are common--one for hard-of-hearing children and the other for deaf children.

Deaf children are generally three to four years educationally retarded (Kirk, 1962). A contributing factor to this educational retardation may be that a large amount of school time is spent in developing speech, language, and speechreading (lip-reading) skills. It is possible that automated instruction might be an important factor in improving educational achievement in this group of children.

Researchers in this field have been primarily interested in the processes and disorders of hearing rather than the effects of the hearing disability on school achievement and adjustment of the individual (Quigley, 1962). This preoccupation with disability provides educators with little information on which to base instructional programs. However, deaf and hard-of-hearing children have certain needs that could be met by programming and by adaptations of student-subject matter interfaces.

Since the deaf child lives in a world of auditory language deprivation, it is difficult for him to acquire general language efficiency. An interface programmed for language instruction would be valuable for the education of the deaf. Some preliminary work has been done in this regard. Stuckless and Birch (1964) studied the efficacy of programming for the development of written language in the deaf. They found that grammar could be taught, through programmed instruction in less than half the time that traditional teaching methods required. They also found that the grammar of adolescent deaf children, in whom language had been previously established, could be significantly improved through programming.

The development of speech is important for the deaf child if he is to be able to communicate efficiently with hearning persons. Since the deaf child cannot effectively utilize auditory feedback in developing speech, other cues must be employed. In considering a design for an interface that would produce adequate speech, the child would be presented with a visual stimulus which he would pronounce. Utilizing the visible speech cathode-ray tube translator, the oral response could be transformed into a graphic pattern. A graph of the correct response could be super-imposed on the student's response for purposes of comparison. Different phonetic sounds could be paired with visual symbols. If the stimulus is mispronounced, the appropriate symbol would appear as a cue on the display mechanism. The learner would then pronounce the stimulus until a correct response is elicited.

Speechreading, or lip-reading, is another important communication need of children with auditory disabilities. Speechreading is dependent on the child's ability to analyze in a meaningful way various lip and facial movements produced in the act of talking. The child must learn to read all configurations of lips and facial expressions. An interface could be programmed to display representative facial types pronouncing the same or different words and phrases. This would be helpful in teaching discrimination in speechreading.

In classroom situations, a communication problem is presented when a student responds to the teacher's questions. Very often, the other members of the class either misinterpret or do not understand the response. This situation could possibly be remedied by using the graphic pattern detector. The student could write his response at his desk and have it appear on a screen for the cognizance of the entire class.

The interface concept could also be applied to the hard of hearing. The majority of these children do not differ from hearing children in intelligence or school achievement and should be educated in the regular classroom (Streng, 1953). It is sometimes necessary, however, to provide special instruction in communication. These children need training in speech, language, and speechreading. The programs described above may be applicable to the hard of hearing with the exception that amplified auditory signals could be added to the visual cues. Programs designed for children with normal hearing could be utilized. An interface that would provide training in auditory discrimination would be helpful to the hard of hearing since many of these children need assistance in interpreting sounds.

Children with Behavior Deviations

Children with behavior deviations are generally described as being either socially maladjusted or emotionally disturbed. These are generic terms which encompass various types of rather complex anomalous personal behaviors. It is not within the scope of this discussion to dwell on rationale for innovations in the design of student-subject matter interfaces.

These children have difficulty with interpersonal relationships. This is particularly true in the typical classroom situation in which the child must interact with the teacher and his classmates. The resulting problems generally lead to ineffective learning--if indeed, learning takes place at all. It seems likely that an automated interface, being impersonal, would appeal to such children and possibly be more effective than the teacher.

Quay (1963) advocates the use of programmed instruction for the withdrawn child because it is highly structured, can require simple responses, and allows for a maximum of correct responses. In programming for the withdrawn child, it would be wise to use branching techniques to keep anxiety producing, incorrect responses to minimum.

Teaching machines are also advocated by Quay (1963) for the acting-out child. Instruction should be programmed to provide more repetition than the ordinary child would receive. Quay states that these children are novelty-seekers; and as such, proposes the use of "teaching machines which provide not only the correct answer as the reinforcer but at the same time light up, ring bells, and perhaps even shoot fireworks" (p. 30). The implications for the stimulus change capabilities of certain interfaces are quite apparent.

The Mentally Retarded

Heber (1961) states that, "Mental retardation refers to sub-average intellectual functioning which originates during the developmental period and is associated with impairment in adaptive behavior"(p.499). The mentally retarded are generally classified in two groups for purposes of education: (1) the educable mentally retarded (EMR), who generally have IQ scores between 50 and 75 and can obtain functional literacy but will have learning difficulties in the regular grades, and (2) the trainable mentally retarded (TMR), who have IQ scores between 25 and 50 and cannot obtain functional literacy, but will be able to attain self-help skills, limited social skills, and minimal economic efficiency.

Since the differences between retarded and normal children are primarily intellectual in nature, few specific problems in the physical design of the interface should be encountered. The most important concern should be in the programming of information for the interface. Therefore, the bulk of this section will deal with considerations in programming for the retarded.

Quay (1963) reports that there are qualitative and quantitative differences between the learning characteristics of trainable retardates and normal children, but that educable retardates may learn some tasks in the same fashion as normal children but may differ in the way in which they learn others. This implies that, although some would require modification, programs that are designed for normal children could be used without modification for the EMR. Stolurow (1961) supports this notion. He states that wide ability ranges could be served by a single program provided that the learner has obtained the minimum level required for the program and that adequate provision for review is made. In addition, the program might be adaptable so that different instructional techniques could be used with different students, depending on their performance during training. Branches could be built to account, in part, for individual differences (Coulson and Silberman, 1962). Stolurow (1960) lists two additional implications in programming information for the mentally retardates and normals; and (2) The interface for the mentally retarded should be designed to provide for overt responses.

The education of the mentally retarded is intended to make provisions for individual differences. The interface that is designed to yield information regarding the performance of retardates on learning tasks would provide educators and psychologists with valuable information, related to their learning characteristics, that would have implications for instructional practices. Thus, a major function of the interface would be as an experimental device that could control teacher variables, apply different motivational techniques, be used to study various aspects of learning, and provide a record of the subject's performance on the assigned tasks (Jenson, 1962).

Studies have not shown that the learning characteristics of brain-injured children differ from those of retardates with other etiologies (Quay, 1963). Some educators believe that special teaching techniques should be utilized with brain-injured retardates. Strauss and Lehtinen (1947) propose three principles for the education of brain-injured children: (1) Reduce the space in which the learning situation takes place; (2) Control distracting stimuli; and (3) Present information to be learned so that it receives the child's full attention. Gallagher (1960) proposes that the brain-injured child should be provided with an individual tutor for the most effective education. An interface could be constructed to incorporate both of these views. The interface could be located in a "student office" that is free from distracting stimuli and could be constructed in such a manner that attention would be focused only on the display and response mechanisms.

Classical conditioning is quite effective in training the TMR and programs can be developed along the lines of this methodology. O'Connor and Hermalin (1963) have shown that conditioning can be used effectively in training the TMR to read simple words. Programs could be developed for teaching a protective reading vocabulary following a classical conditioning paradigm. For example, the word danger would appear on the display mechanism. The child would hear the word pronounced and would, in turn, be required to pronounce it. He would then receive a reward. This process would be repeated until the child responds to the written word without hearing the pronounciation. Pictures of dangerous situations incorporating danger signs could be used as stimuli in order to place the concept in its proper context.

Clarke (1958) lists several principles, based on research conclusions, that are applicable to the training of the TMR. Among these, (1) Meaningful visual incentives should be employed; (2) Tasks should be divided into their simplest components; (3) Correct movements should be stressed; (4) Tasks should be over-learned; (5) Emphasis should be on accuracy rather than speed; (6) Learning should be spaced rather than massed; and (7) Verbalization of concepts the child learns should be stressed for effective learning. These principles should be considered when developing programs for trainable retardates.

Training programs for the TMR often culminate in their placement in a sheltered workshop. The tasks performed in these workshops are manual in nature. Interface devices could be developed to provide training in manual manipulation and neuro-muscular integration.

Learning Disabilities

Perhaps one of the more valuable functions of a specially designed interface would be as a tool for the diagnosis and remediation of learning disabilities. "A learning disability refers to a retardation, disorder, or delayed development in one or more of the processes of speech, language, reading, writing, arithmetic, or other school subjects resulting from a psychological handicap caused by a possible cerebral dysfunction and/or emotional or behavioral disturbances and not the result of mental retardation, sensory deprivation, or cultural or instructional factors"(Kirk, p. 263). A child is classified as a reading disability if, for example, he has the intellectual capacity to learn to read, but does not learn after ordinary instruction.

A computer-operated interface could possibly be designed to diagnose learning disabilities. Available information concerning various learning disabilities could be stored in the computers. The interface would be programmed to administer a battery of diagnostic tests and record the results. The computer would then analyze these results on the basis of the stored information and make a diagnosis of the specific learning disability. Specially designed programs would be designed to remedy different learning disabilities.

The Mentally Advanced

Previously in this appendix, variations in interface design and programming considerations were proposed for the purposes of adaptation to various disability groups. This approach is not necessary when dealing with the gifted since they have few, if any, physical or mental disabilities that would warrant similar proposals. However, there are several characteristics of the mentally advanced that should be brought to the attention of the designer of instructional programs. These characteristics may have some bearing on the method of presentation, and content of programs designed for their use. Among these, Kirk (1962) states that gifted children: (1) learn faster than the average child, thus requiring less repetition to learn the same material; (2) have superior reasoning ability enabling them to see relationships and grasp ideas more readily; (3) have a large vocabulary and good verbal ability; (4) have a broad fund of information; (5) have insatiable curiosity; (6) have wide ranges of interests; and (7) are generally observant. Student-subject matter interfaces, properly designed and programmed, e.g., simulated sciency experiments and voice-detection word games, could show great value when used with the mentally advanced.

Conclusion

An attempt has been made to apply the concept of the student-device interface to special education. The notions presented here merely serve as a spring-board for further thinking. The only limitations imposed are the lack of ingenuity and the sophistication of technology. While the preceding discussion may seem unrealistic to some, special educators deal with exceptional children, and in so doing, should seek exceptional devices to assist them in the performance of their task.

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Part B

Force Lesson for Science Instruction

The following lesson is an example of what is termed a special purpose interface device which would be useful in teaching in a limited area of science and would have no widespread applicability.

Consider a lesson designed to show one aspect of the term force as used in physics. In this aspect of the term force, it is desired that the student learn that the displacement of a spring is a measure of the force exerted. Figure A.1 illustrates such a special purpose spring. In stimulus and response terms, when the student is shown a spring being stretched first one inch from its rest length, he should learn to respond that the force has been doubled. He should learn that there is a qualitative difference in the muscular effort required to double the extension. Thus in answer to the question, "What did you have to do to double the extension of the spring?" the student should answer, "I had to pull harder." Another aspect of the terminal behavior being sought is the intuitive ability

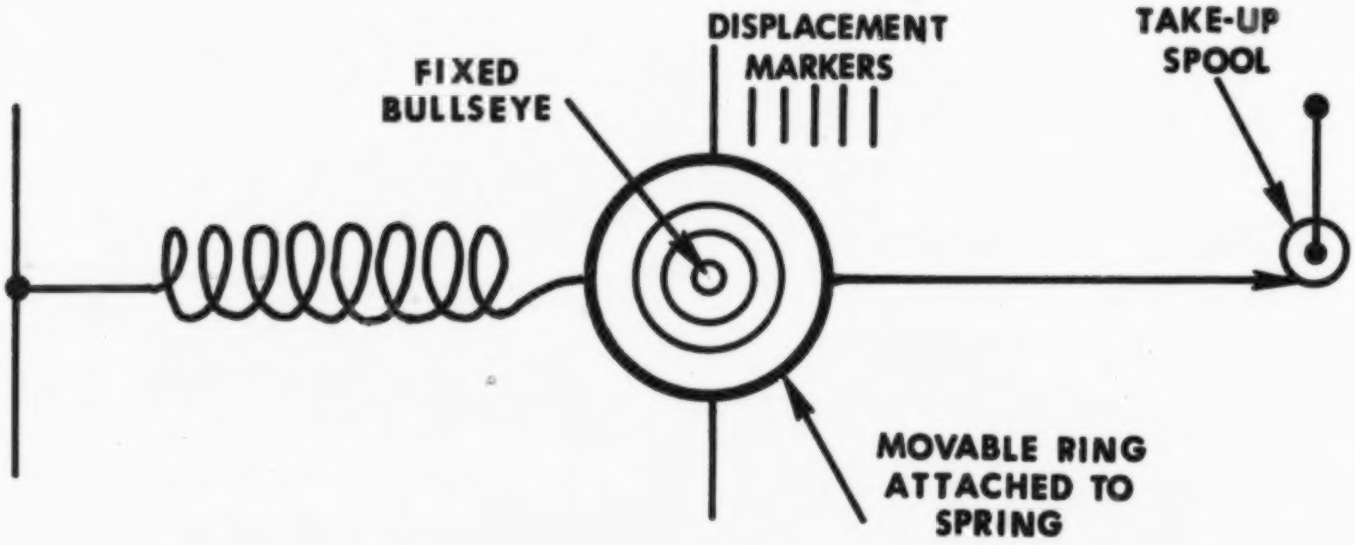

Figure A.1. A device for developing qualitative responses relating the force exerted on the take-up spool and the extension of the spring. By varying the initial conditions of the stiffness of the spring and its relaxed extension, different problems may be presented to the student.

to utilize components of one or more forces to give a desired resultant force. Thus, if three springs are holding a ring in the center of a display table, when one of the springs has its tension altered, the ring will move from the center of the table. The student then is required to alter the tension in the other two springs by adjusting manual controls which are available to him. A display showing the tension in each spring and the component of force in a chosen direction can be used as a prelude to a more quantitative understanding of the addition of forces. The number of springs used in this lesson is to be determined by gradual progression on the one hand, and by diminishing returns on the other hand, i.e., it is not clear that much additional learning will take place by increasing the number of springs past four or five. In terms of student interest and motivation, a six-springer (seven, eight, ...?) may be useful.

Determination of Entering Behavior

The student must have the ability to adjust both the springs and the spring controls upon direction. This ability should be determined by asking him to perform simple operations on the table with one adjustable spring and one fixed spring in place. He should be able to read numbers and adjust a control until he obtains a number reading to match a number he has been given in an instruction.

Participation in Terminal Behavior

In this lesson the complexity can be controlled such that the student can perform the terminal behavior in a simplified form during the determination of entering behavior. With one adjustable spring and one fixed spring attached to the ring he can adjust the tension in the spring so that he returns the ring to a bullseye in the center of the table. A film showing a contest in which the ability to hold the ring in the center is necessary to save the hero's life will enable the student to avoid boredom by identifying his activities in the lesson with the elements of the story.

Generalization Display.

An element of generalization is introduced by using various types of springs in varying numbers. Another element of generalization may be introduced by using other natural springs such as pieces of rubber, thin wire, and nylon line. The tension display can be provided by a digital meter, an analog meter, an oscilloscope, a tone from an oscillator, a color hue, or light intensity. This enables the student to generlize that the force is independent of the display mechanism which informed the student of the magnitude of the force.

Gradual Progression

1. Establish the response required to extend a single spring. (pull harder.)
2. Couple the word force to that which causes the spring to become extended.
3. Develop ability to measure extension numerically.
4. Develop ability to exert approximate force required for various extensions.
5. Associate intuitive muscular concept of more and less force to readings of a tension transducer (digital).
6. Use manipulatory knob to alter readings on tension readout and develop relation that doubling force doubles extension.
7. Develop response that force is required to move or extend the spring and that when the spring is held stationary in an extended position it must be pulling back on the ring as hard as the student is pulling on it.
8. (Figure A.2) Use two wires to develop concept that each wire supplying 1/2 force needed for a given extension is the same as one wire supplying the entire force.

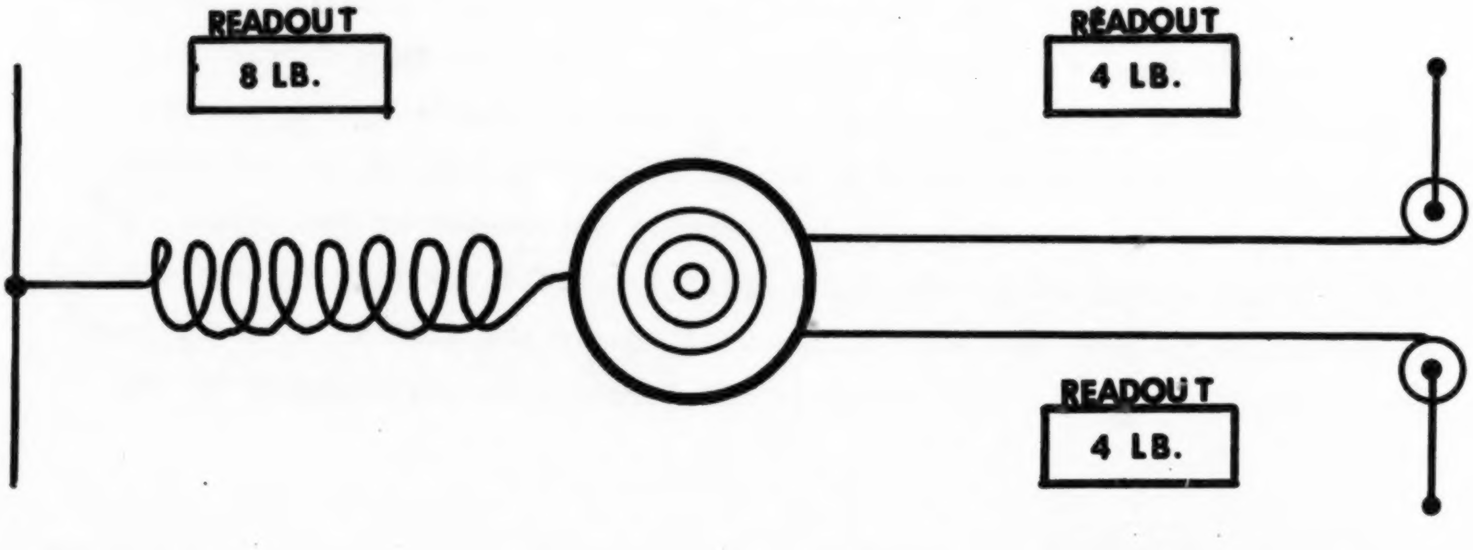

Figure A.2. A modification of device in Figure A.1 to show the quantitative as well as qualitative relation between the tension in the two wires and the force exerted on the spring.

9. (Figure A.3) Put the wires at an angle to the line of the single wire and have the student make the discrimination (with the aid of the readout and muscular comparison) that the force on both wires exceeds that which the spring applies to the ring.

10. Have student make discrimination that no attainable amount of force on the wire will allow them to be at right angles to the spring if the spring is to be in an extended position (See Figure A.4).

11. Develop responses that the only part of the force that counts is the amount of force in the direction of the spring since the other components cancel each other (See Figure A.5).

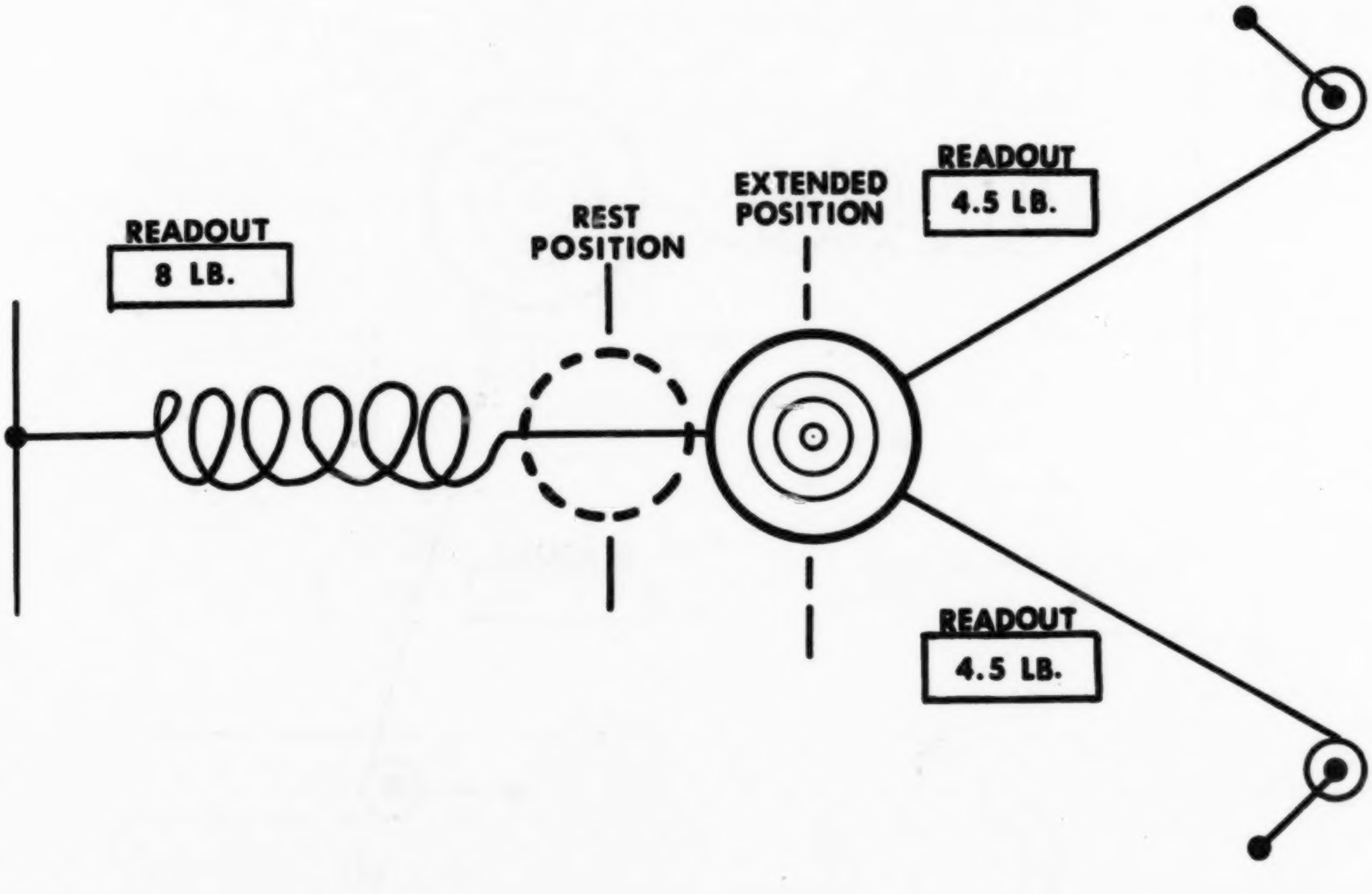

Figure A.3. A modification to show that the sum of the tensions in the wires may be greater than the force on the spring and that the effect is dependent upon the angle between the wires.

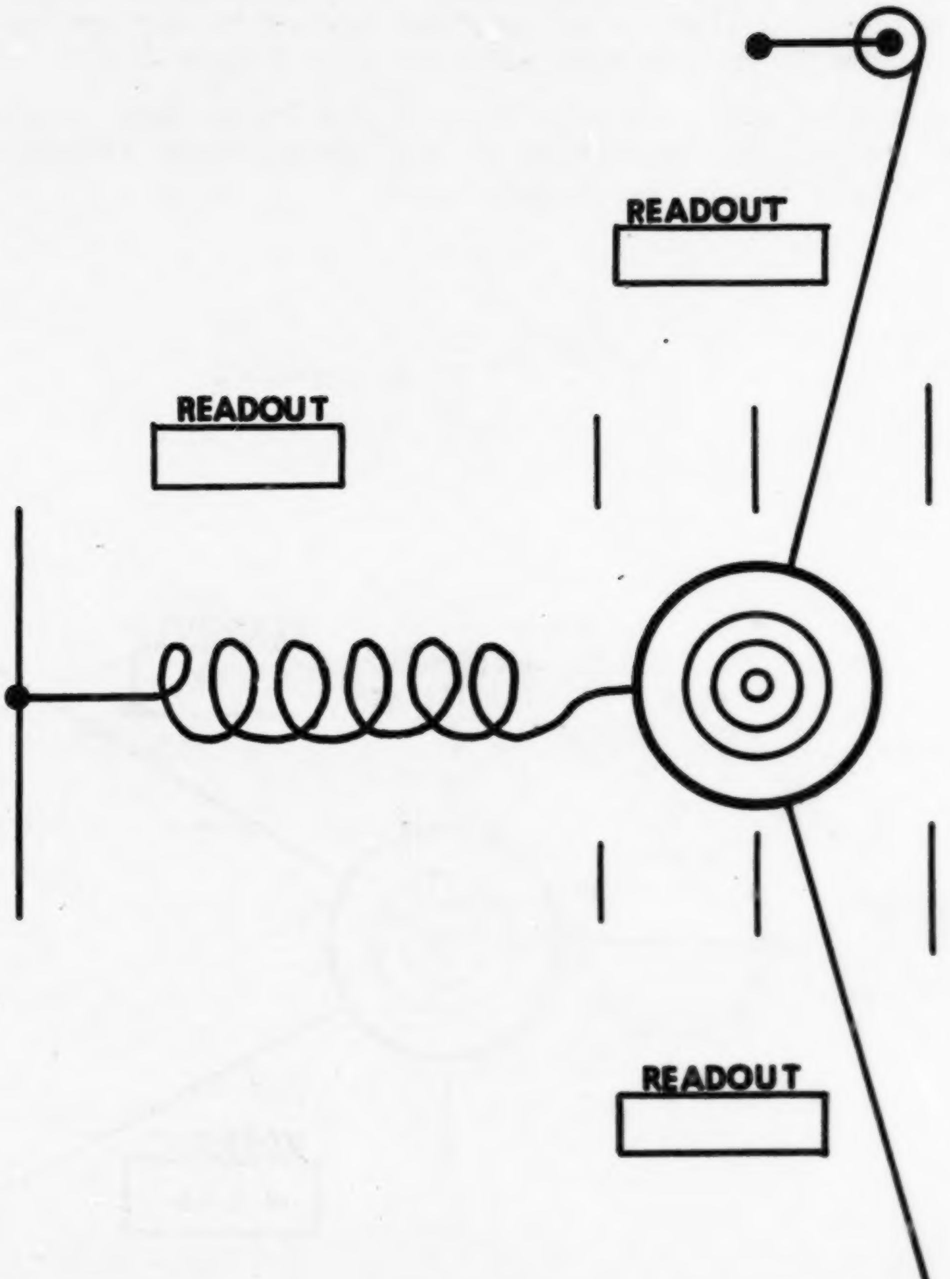
READOUT
READOUT
READOUT

Figure A.4. Device in position approached for very large tensions in the wires. Student should observe that no matter what the tension, the wires cannot be brought perpendicular to the axis of the spring.

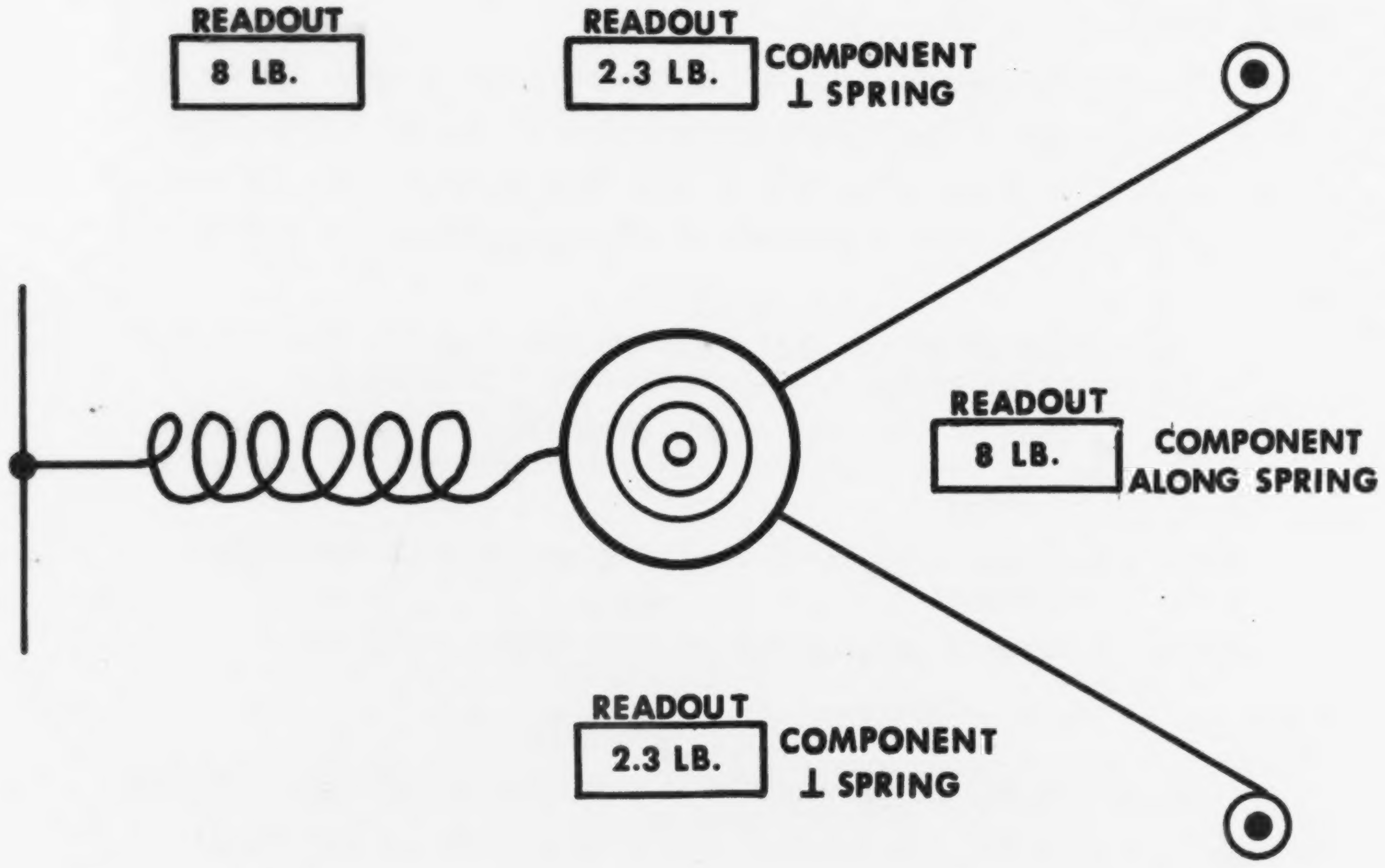
READOUT
8 LB.
READOUT
2.3 LB.
COMPONENT
⊥ SPRING
READOUT
8 LB.
COMPONENT
ALONG SPRING
READOUT
2.3 LB.
COMPONENT
⊥ SPRING

Figure A.5. This figure shows additional readout components used to develop quantitative aspect of vector addition and subtraction of forces applied to the spring by the wires.

For more advanced students, the following should be added.

12. Use readouts (Figure A.5) showing the components of force along the spring and at the right angles to the spring. Have student develop ability to adjust force readings to obtain extension by paying attention to components in direction of desired extension.
13. Place a different student on each wire and the spring with a take up spool. For a change in the displacement by one student, the task of the other is to adjust his wire to return the ring to the starting position as quickly as possible. Points are scored by least total time during the game.
14. Extend above sequences to more wires and more springs.

Reinforcement

Usually activities with gross manipulative properties which result in a change in the display properties of the interface (numerical readout with clicking noises) are self-reinforcing. In addition, the following reinforcers are easily integrated into the lessons:

1. A light comes on in the bullseye when the ring has been returned to its starting position or to some chosen position.
2. Record is kept of the time to put ring into designated position. It is expected that shortened times to completion of task will prove reinforcing.
3. After completion of tasks a free play period with the force table is permitted.
4. Provide extrinsic reinforcers if none of the above work.

Prompting

Prompting may be provided by a trial button so that different combinations of force are applied with a commentary on the result. These can be structured in such a way that limited amounts of information are provided at the student's option. For the responses which do not require manipulation of the force applied to the ring, the manipulatory sequences should provide the basis for the verbal responses. Conventional prompts such as emphasizing certain words, offering a limited choice, colored guide lights, etc., may be used.

Fading of Prompts

As the repertoire of the student increases and he is able to use the concepts of force, equal force, greater force, direction of the force, he should be able to use the readout numbers and the position of the center ring to monitor the success of his performance. The use of prompts which are apart from the gradual progression procedure should be reduced in intensity. For example, the information supplied by the trial button should become less informative in indicating the response desired, until finally the trial or hint button will supply informative information which is not directly relevant to the task. Prompts such as guide lines, colored lights, can have their stimulus intensity reduced.